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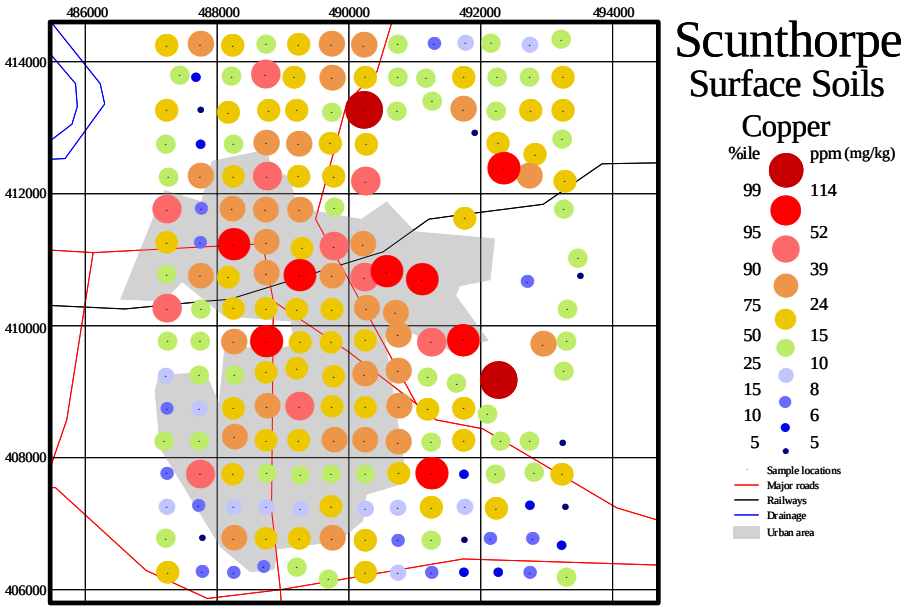
Geochemical baseline data for the urban area of Scunthorpe

Urban Geoscience and Geological Hazards Programme

Internal Report IR/02/083



BRITISH GEOLOGICAL SURVEY

INTERNAL REPORT IR/02/083

Geochemical baseline data for the urban area of Scunthorpe

K E O'Donnell

Contributor/editor

F M Fordyce

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Parent Body

Natural Environment Research Council, Polaris House, North Star Avenue, Swindon, Wiltshire SN2 1EU

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The soil geochemical data presented in this report (and other urban reports from this series) are from individual sites, which were sampled as part of a baseline geochemical survey. The results should only be used to set a regional context, not as the basis for interpretations concerning specific sites. Interpretations relating to specific sites should be based on follow-up investigations. The data in this report, in addition to all geochemical data held by BGS, are available under licence. Their use is subject to the terms of a licensing agreement.

Foreword

This report is a product of the British Geological Survey's (BGS) Geochemical Surveys of Urban Environments (GSUE) project. The work is funded by the UK Government Office of Science and Technology and is part of the national Geochemical Baseline Survey of the Environment (G-BASE) programme. The report forms part of a publication series, which aims to make GSUE urban soil chemistry data publicly available with a minimum of interpretation, displaying the data as a series of graduated symbol maps.

A number of urban centres have been surveyed to date using systematic soil sampling procedures. These are indicated in the figure below. Wolverhampton, Manchester and Glasgow were sampled as part of larger multi-disciplinary projects.

Urban centres sampled to date by the GSUE project.

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Summary

This report presents the results of an urban soil geochemical survey of Scunthorpe carried out by the British Geological Survey (BGS) during 1995. The study was undertaken as part of the BGS systematic Geochemical Surveys of Urban Environments (GSUE) project. The concentrations of many potentially harmful elements (PHE) such as As, Cd, Cr, Ni and Pb are enhanced in city environments as a result of urbanisation and industrial processes and their distribution is of concern under current UK environmental legislation.

The GSUE data provide an overview of the urban geochemical signature and because they are collected as part of a national baseline programme, can be readily compared with soils in the rural hinterland to assess the extent of urban contamination. The aim of the present study was to generate urban soil geochemistry information for Scunthorpe to aid planning and development.

Urban surveying was based upon the collection of samples on a systematic 500 m grid. Soils were sampled at a density of 4 per km^2 across the built-up area. Samples were collected from open ground as close as possible to the centre of each 500 m grid cell. A summary of the sampling and analytical protocols adopted for Scunthorpe is presented in Table 1.

Preliminary interpretations of the data in relation to the past and present industrial history of Scunthorpe are presented in this report and demonstrate elevated concentrations of several PHE in association with the transport network and former industrialised areas of the city. However, it should be noted that concentrations of elements such as arsenic are naturally enhanced in Scunthorpe soils as a result of the underlying ironstone bedrock.

Table 1 Summary of the Scunthorpe soil sampling strategy

Date Sampled:	Summer 1995
Area Sampled:	24.5 km^2 (min E 487210; max E 493500; min N 406160; max N 414330)
Sample Density:	1 per 0.25 km^2
Number of Samples:	196 surface (0.05 – 0.20 m) and 192 profile (0.35 – 0.50 m) soils
Elements Determined by XRFS: *(elements in italics determined in surface samples only)*	*Al_2O_3, CaO, SiO_2, P_2O_5, K_2O, TiO_2, MgO,* Fe_2O_3, MnO, Cr, Mo, Pb, Zn, As, Cd, Cu, Ni, Sb, U, Ba, Co, Sn, V.

XRFS = X-Ray Fluorescence Spectrometry

1 Introduction

This report summarises the results and methodology of a soil geochemical survey of the urban area of Scunthorpe, undertaken by the British Geological Survey (BGS) during 1995 as part of the Geochemical Survey of Urban Environments (GSUE) project. The GSUE project forms part of the national strategic geochemical survey of Great Britain and Northern Ireland, the Geochemical Baseline Survey of the Environment (G-BASE) programme (Johnson and Breward, 2004).

The programme is undertaking a systematic regional geochemical survey of soils, stream sediments and stream waters of the British Isles at a sample density in rural areas of 1 per 1.5 – 2 km^2. The data provide information on the surface chemical environment, which can be used to define environmental baselines and the extent of surface contamination and are published as a series of regional geochemical atlases for the country (see for example British Geological Survey, In Prep). The distribution of chemical elements in the environment is of concern because although many are essential to life, several including As, Cd, Cr, Ni and Pb are potentially harmful to plants and animals in high doses. Concentrations at any location are often controlled by factors such as geology, vegetation, soil forming processes and climate. In addition to natural sources of these elements, environmental concentrations can be enhanced by anthropogenic activities such as mining, industrialisation, urbanisation and waste disposal. The G-BASE data have a wide range of applications, including the assessment of risks to human health, with respect to potentially harmful elements (PHE) through environmental exposure.

The concentrations of many potentially harmful elements (PHE) are enhanced in urban environments as a result of atmospheric and terrestrial contamination and the nature of urban ground, which is often disturbed and in-filled and bears little relation to the soils, bedrock and superficial cover of the surrounding rural hinterland.

As part of the G-BASE programme, the GSUE project undertakes systematic soil surveys to define city-wide geochemical signatures over selected urban areas including that of Scunthorpe (Figure 1).

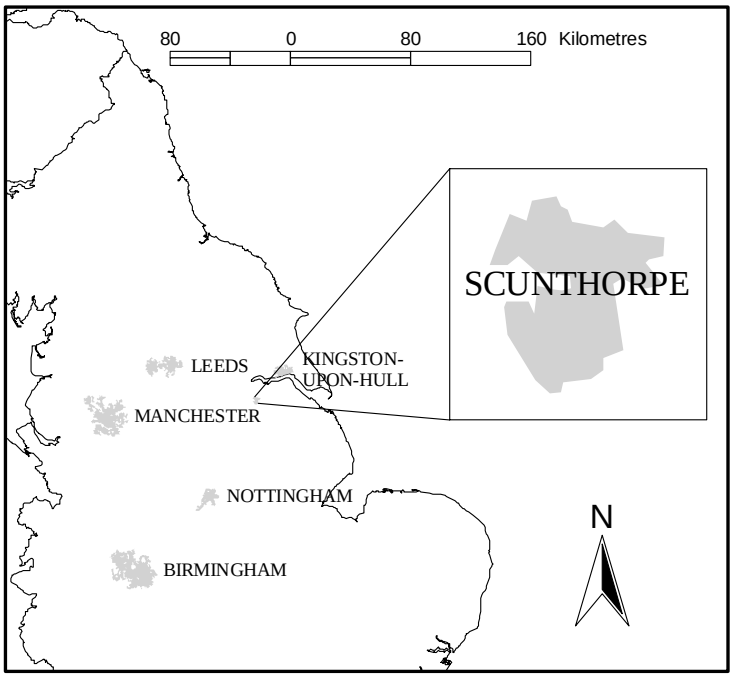


Figure 1 Location map for Scunthorpe

The town of Scunthorpe is located within the local government administrative area of North Lincolnshire and has a population of around 62,000. The principal industry has traditionally been steelmaking, however, in more recent times, other industries have gained in importance.

The distributions of approximately 23 major and trace elements including several PHE in the surface environment of Scunthorpe are described in this report in relation to present and historical land use. The concentrations of the elements are also considered in terms of the underlying geology and placed in context with respect to the typical rural background concentrations obtained from G-BASE regional soil data sets from the surrounding area.

2 Study Area

2.1 AREA SAMPLED

An area of 24.5 km^2 was surveyed during the summer of 1995, in which a total of 196 surface soils (0.05 – 0.20 m depth) and 192 profile soils (0.35 – 0.50 m depth) were sampled. This extends from BNG references 487210 m east to 493500 m east and from 406160 m north to 414330 m north (Table 1). The survey area is shown in Figures 2 and 3.

2.2 HISTORICAL LAND USE

The development of Scunthorpe, from five North Lincolnshire villages, was promoted from 1860 onwards by the exploitation of the ironstone on which the town lies (Figure 4) for steelmaking[1]. Scunthorpe became one of Britain's major steel-producers, however, the industry is now suffering a decline. Consequently, the development of new forms of manufacture, within a number of industrial parks, has become key to the economic progress of the town. These include food processing, electronics, furniture, pharmaceuticals, petrochemicals, plastics, clothing, power generation and light engineering. Despite this, steelmaking continues to employ the largest proportion of the workforce in Scunthorpe. The surrounding countryside is dominated by agricultural land, but has also been exploited for its sand and gravel resources.

The steel works are located to the east of the town (Figure 3), south of the railway line and east of the A1029 road; the road and railway form the western and northern confines of the workings respectively. To the east of the steel works are opencast ironstone workings, whilst industrial estates and a retail park are located along the western margin of the steel processing site. The Foxhills industrial estate is located in British National Grid (BNG) square 488000E / 413000N, north of the main built-up area and there is also an industrial estate close to the northwest extent of the urban area in BNG square 487000E / 411000N. The Southpark industrial estate is located towards the southwest corner of the area sampled (BNG square 487000E / 407000N).

2.3 SOLID AND SUPERFICIAL GEOLOGY

Geological information for the Scunthorpe area was obtained from the BGS 1:50 000 series maps for the area (Institute of Geological Sciences, 1982; Institute of Geological Sciences, 1983) and the BGS digital DigmapGB® database. The town of Scunthorpe largely overlies the Frodingham Ironstone, which underlies the central region of the study area (Figure 4). The Frodingham Ironstone is a member of the Lower Jurassic Lias Group and crops out in Lincolnshire to the south of the River Humber for a distance of 17 km (Slater and Highley, 1976). Ironstones are defined as sedimentary rocks containing more than 15% iron (Young, 1993), but there are various categories of ironstone based on lithology and texture. The Frodingham Ironstone is an ooidal ironstone, defined by the presence of ferruginous ooliths, and was formed in a shallow marine environment. The formation is around 8m thick and is comprised of layered sequences of mudrocks (mudstones, shales, clays), sandstones, limestones and oolites. The ooliths are very distinctive as they are ovoid or kidney-shaped, as opposed to the typical concentric shapes that are found in ooidal limestones. Fossils are abundant in many beds and include bivalves, brachiopods and ammonites. The groundmass typically contains siderite, calcite and kaolinite minerals and the beds are naturally enriched in phosphorus (Goldring, 1974). The upper beds of the formation are significantly limonitised, due to oxidation-leaching, which is generally associated with an enrichment of the iron content (Slater and Highley, 1976).

Beneath the western edge of the sampling area are Triassic and Lower Jurassic mudstones and limestones (Figure 4). The Jurassic beds are also part of the Lias Group, with shales and clays overlain by gritty, fossiliferous limestones, grading into the Frodingham Ironstone. The eastern margin of the study area is underlain by the Charmouth Mudstone Formation (comprised of clays) and the Pecten Ironstone (Figure 4). The Pecten Ironstone is a brown ooidal ironstone, which hosts a range of fossils and also contains nuggets and crystals of pyrite towards the base of the sequence (Whitehead *et al.*, 1952). Middle Jurassic mudstones and limestones, of the Redbourne Group are found in the northeast corner of the sampling area. Quaternary Blown

[1] http://www.visitoruk.com/scunthorpe/index.htm

Sands are widely distributed throughout the area. They cover parts of the Redbourne Group, much of the Lower Lias in the southeast corner of the area and more restricted spreads on the eastern and western margins of the area. Blown Sands are also found over the Frodingham Ironstone, in a region through the centre of the area, which forms the edge of a topographic low that covers the eastern part of the urban soil sampling grid (Figure 5).

There are therefore two dominant soil parent material types for this survey area, the Frodingham Ironstone through much of the central part of the area and Quaternary Blown Sands around the margins, with limited exposures of other Lias Group rock types. The solid and superficial geology are shown in Figure 4 and Figure 5, respectively.

2.4 MADE GROUND

According to data held on the BGS digital 1:50 000 scale DigmapGB® database, available on the Geoscience Data Index (GDI)[2], there is a large region of made ground underlying the northeast section of the urban area, extending across much of the eastern part of the sampling grid (Figure 6). A large part of this area was not included in the urban survey, due to access limitations, as the sample locations in Figure 6 show. The presence of made ground is associated with the steel workings in this area, hence there are likely to be significant levels of ash and other fuel waste within the deposits. Made ground cover also extends into parts of the northwest corner of the sample area (Figure 6).

[2] http://www.bgs.ac.uk/geoindex/

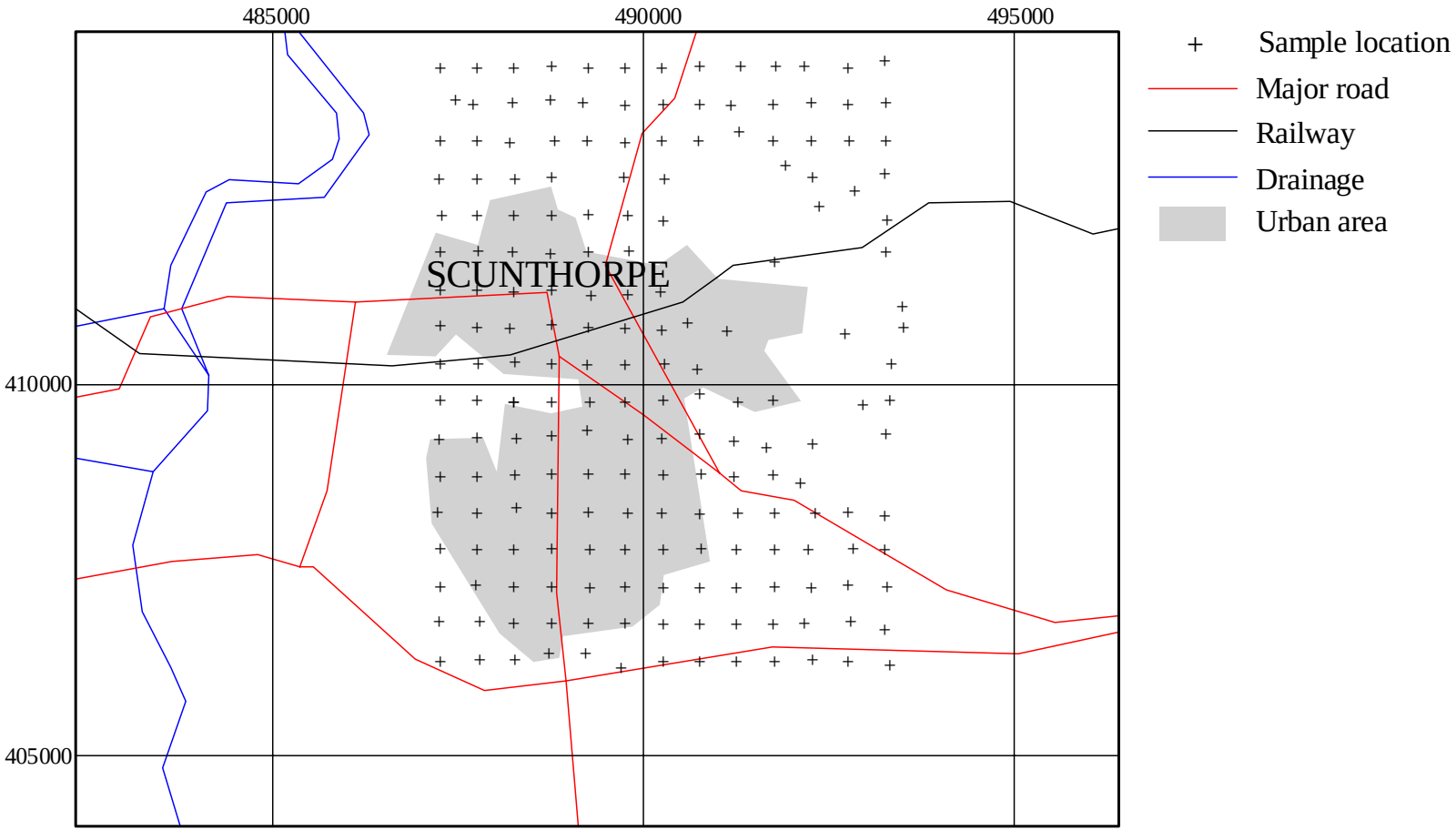


Figure 2 Map of the sampling area (BNG shown at 5 km intervals)

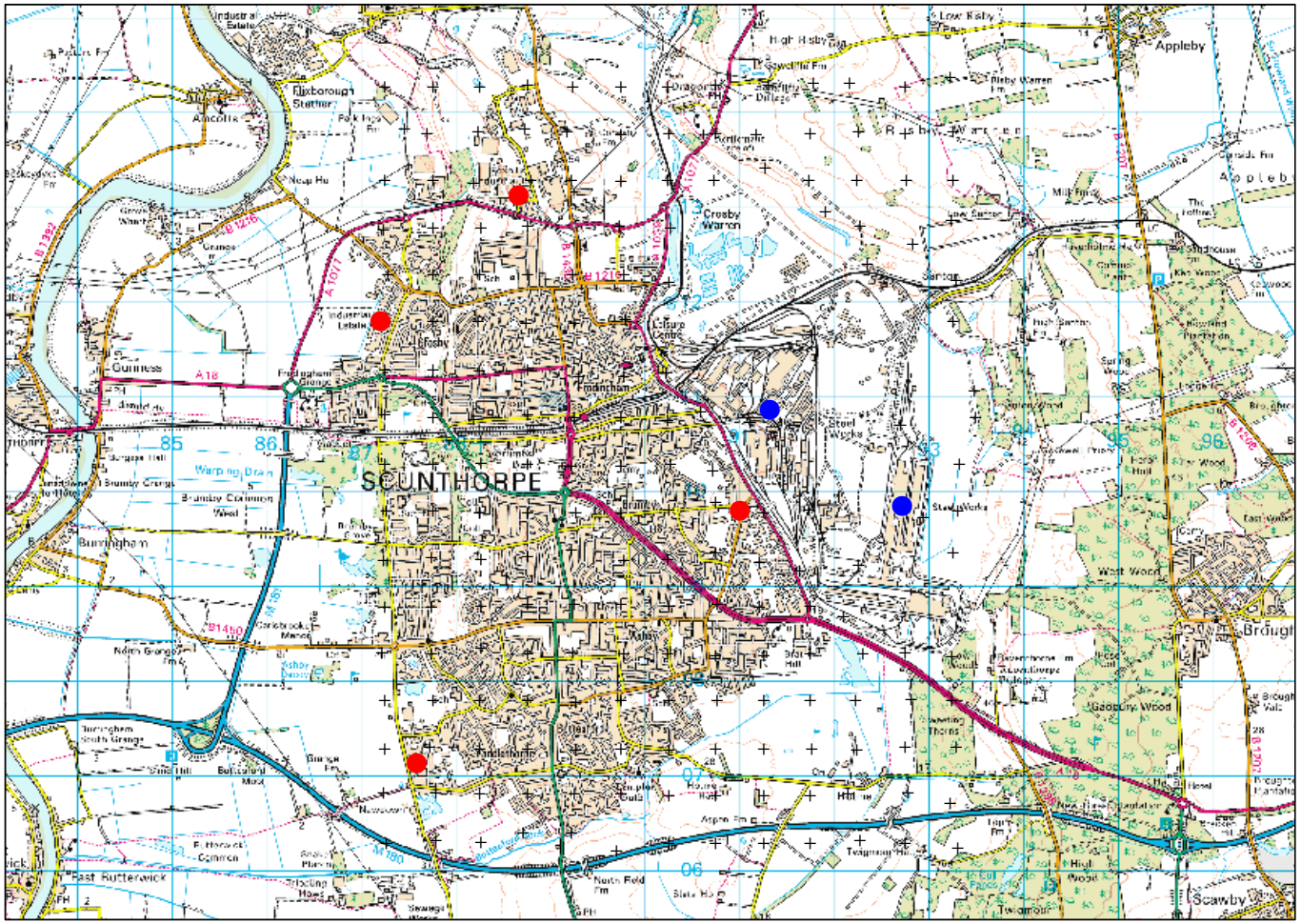


Figure 3 Topographic map of the sampling area (BNG shown at 1 km intervals)

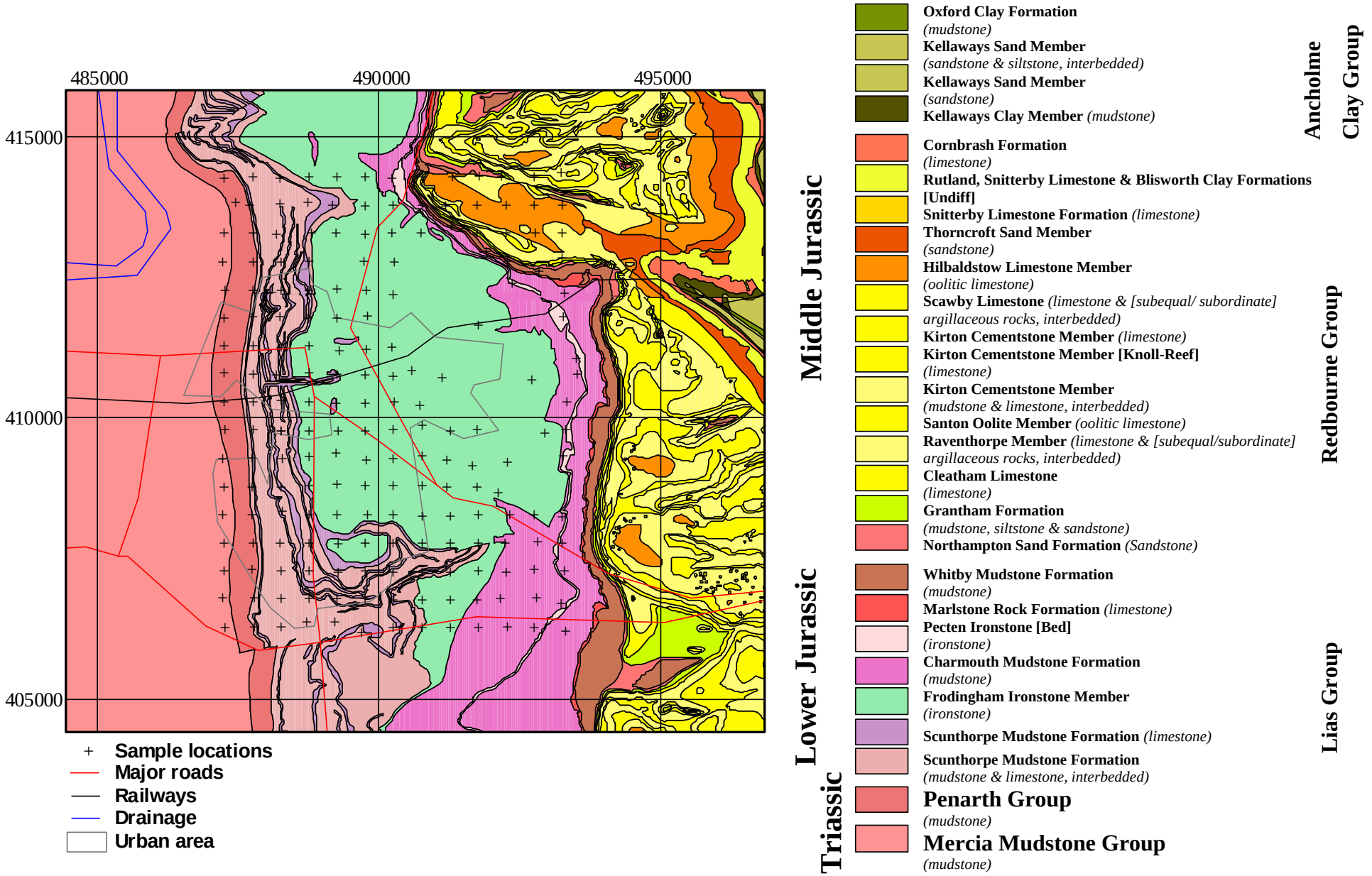


Figure 4 Solid geology map of Scunthorpe and the surrounding area (based on 1:50 000 scale geological map; BNG shown at 5 km intervals) BGS DigmapGB®

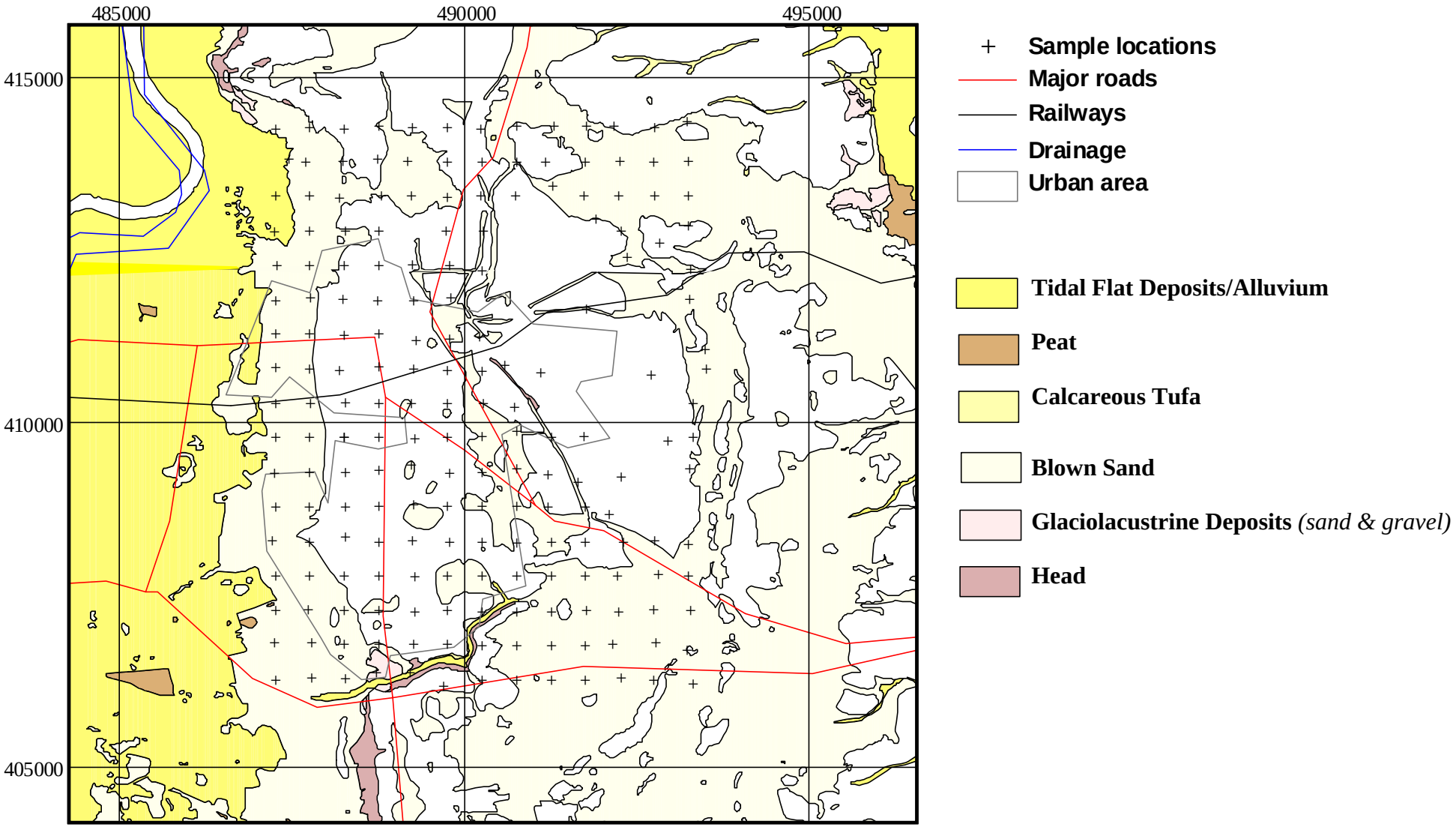


Figure 5 Superficial deposit map of Scunthorpe and the surrounding area (based on 1:50 000 scale geological map; BNG shown at 5 km intervals) BGS DigmapGB®

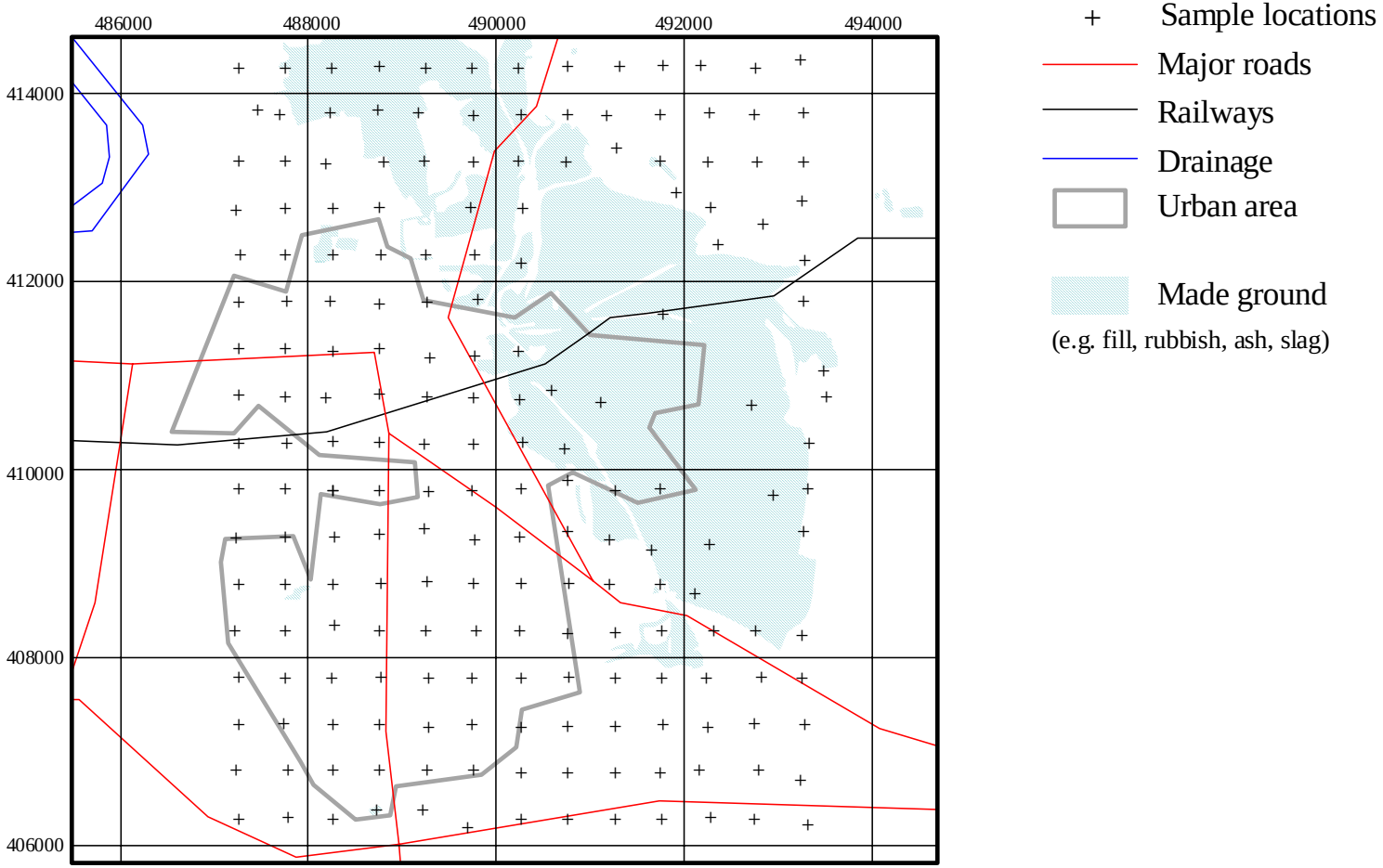


Figure 6 Map of the extent of made ground in the Scunthorpe area (based on 1:50 000 made ground map; BNG shown at 2 km intervals) BGS DigmapGB®

2.5 SOIL TYPE

The National Soil Resources Institute (formerly the Soil Survey of England and Wales) produces soil maps for much of the UK landmass, however, urban and industrial areas have not been surveyed for soil type. Therefore, no information exists on soil type for the main urban area of Scunthorpe, although limited data are available for the outskirts of the urban area (Soil Survey of England and Wales, 1983; Hodge *et al.*, 1984) as follows:

Soil data for the east of England identifies four main soil types in the outskirts of Scunthorpe. A Humo-ferric podzol extends from the southwest outskirts of the town, in a southwesterly direction. This soil type may be present in the southwest part of the area sampled, where blown sands overlie Triassic mudstones (Figures 4 & 5). Humo-ferric podzol is a well-drained soil, with black or dark brown humus and a bleached subsurface horizon above an iron enriched layer. To the west of Scunthorpe, a gleyic brown calcareous alluvial soil is found in association with Quaternary alluvium around the Trent Valley. This soil type appears to terminate on the outskirts of the urban area, as does the Quaternary alluvium (Figure 5) and is unlikely to occur within Scunthorpe.

A typical sandy gley soil is identified to the northeast and southeast of Scunthorpe and may be found towards the far east of the sampling area. A small region of the same soil type also occurs to the northwest of Scunthorpe. These soils are sandy, with a distinct surface soil and a non-calcareous profile soil. To the east of Scunthorpe, a typical brown earth is identified. This soil type is non-alluvial, with non-calcareous loamy or clayey sub-soils. Typical brown earths are also found to the north and south of Scunthorpe.

The Quaternary deposits that overlie the Frodingham Ironstone around the outskirts of the town are largely absent in the central part of the sampling area (Figure 5). Therefore, it is probable that the soils in this region are more directly related to the ironstone itself, rather than the Quaternary deposits. The latter are likely to exert a greater influence on soil types around the margins of the sampling area. Further north of Scunthorpe, towards the River Humber, a ferritic brown earth is identified in association with the Frodingham Ironstone. Ferritic brown earths are naturally acidic and have a bright, ochreous iron-rich sub-soil. They are well-drained, with fine and coarse loamy textures, resting on shattered ironstone at a depth of 0.50 – 0.70 m. It is possible that this type of soil may be more representative of the native soils within much of the Scunthorpe sampling area, than those mentioned above.

In addition to this general Soil Survey information for the area, soil characteristics are also reported as part of the GSUE survey. Basic information for the urban soils of Scunthorpe was recorded on computer-compatible field cards (see Appendix A), which are completed at site during sampling according to standard procedures (Johnson *et al.*, 2003). These contain data such as soil colour, texture, sample depth, clasts that are contained within the soil, as well as land use and any physical contamination that is observed. The field cards are completed using a set of standard database-compatible codes (Harris and Coats, 1992) and the information is held on the BGS corporate geochemistry database. Examination of the field cards for Scunthorpe revealed the likely presence of made ground at several of the sampling locations (see section 2.4). This may influence the geochemistry of particular urban samples, which could have higher or lower elemental concentrations than the surrounding native soils depending on the source and nature of the made ground material and the presence of any contamination.

3 Methodology

3.1 SOIL SAMPLING

Sample sites were arranged on a systematic grid pattern at a density of 4 samples per km^2 across the built-up area whereby each BNG kilometre square as defined from 1:25 000 scale topographic maps (Ordnance Survey®) was split into four 500 m x 500 m sub-cells. Samples were collected from open ground as close as possible to the centre of each 500 m cell. Sample spacing was kept as regular as possible, namely 500 m apart, but was constrained by the actual conditions that were encountered on the ground (such as buildings and other constructions). Typical locations for sampling included gardens, parks, sports fields, road verges, allotments, open spaces, schoolyards and waste ground. Whilst attempts were made to select the least disturbed area of open ground as close as possible to the centre of the 500 m cell, contamination was not purposefully avoided as the aim of the survey was to provide an overview of the urban geochemistry and not to establish a 'near natural' geochemical baseline.

Soil samples were collected using a Dutch style hand auger with a 15 x 3 cm bore. Two samples were collected from different depths at each site. Surface samples were labelled A and were collected from a depth of 0.05 – 0.20 m. Deeper 'profile' samples were labelled S and were collected from the same auger holes as the A samples from a depth of 0.35 – 0.50 m (Johnson *et al.*, 2003). Both A and S samples were made up of a three point composite collected on the diagonal of a 2 x 2 m square. Duplicate sampling is described in section 3.3.2 of this report.

As indicated in section 2.5 above, information about the soils is recorded at each site on field cards and the sample locations are stored in the BGS corporate geochemical database where they can be retrieved via a user-friendly front-end (Harris and Coats, 1992).

3.2 SAMPLE PREPARATION

Samples were air and then oven dried at temperatures below 20ºC and then sieved. Surface soils were sieved to obtain the <2 mm fraction and profile soils to obtain the <150 µm fraction to be compatible with G-BASE regional <150 µm stream sediment data. The sieved material was coned and quartered and a split of the sample was ground using an agate ball mill until 95% reached a grain size finer than 53 µm. A 12 g split of the ground material was combined with 3 g of elvacite binder and pressed into a pellet for analysis by X-Ray Fluorescence Spectrometry analysis (XRFS) (see section 3.4).

Excess sieved and ground sample material is retained in the National Geoscience Records Centre sample store at the BGS.

3.3 ERROR CONTROL PROCEDURES

The accuracy and precision of the geochemical data were monitored using the methods of Plant *et al.* (1975), which are briefly described below.

3.3.1 Random numbering of samples

Samples were allocated numbers according to a random numbering system (Plant, 1973), but were analysed in numerical order. This allows any systematic error in either sampling or analytical methodologies to be identified and attributed to the appropriate process. At each site the A and the S samples were assigned unique numbers according to the random number lists. Therefore within each batch of one hundred samples there were 50 A and 50 S samples.

3.3.2 Duplicate and sub-samples

Within each batch of one hundred samples, a pair of sample numbers were assigned to a sampling duplicate, resulting in a field duplicate pair for both A and S samples. Duplicate samples were collected using identical sampling methodology adjacent to the original sample. At the sample preparation stage each of the field duplicate samples were split to obtain an analytical replicate sub-sample. Each sub-sample was assigned a different number and treated as a separate sample for analytical purposes.

The collection of field duplicate samples enables the sampling error, or sampling variation, to be estimated, thus providing a measure of the between-sample variance. Analytical replicate sub-sampling allows the analytical error or variance to be estimated as differences in results between the original and the sub-sample may indicate the influence of the sample preparation and analytical process.

The components of variance were estimated using analysis of variance (ANOVA). This statistical technique is used to determine the residual variance (introduced by sub-sampling, sample preparation and chemical analysis); the between-sample variance (attributed to within-site variation and variability introduced during sample collection); and between-site variance (representing the environmental variation in element concentrations across the survey area). All of the analyses form part of a single randomised dataset and a random nested model of ANOVA was therefore used (Snedecor and Cochran, 1989). Due to the relatively low number of duplicate samples collected in a single urban area, the ANOVA calculations were performed using replicate soils collected from 11 different urban centres: Cardiff, Swansea, Stoke, Telford, York, Hull, Doncaster, Mansfield, Scunthorpe, Lincoln and Sheffield (Lister, 2002; Lister, In Prep). A total of 50 replicate sets were measured for urban profile soils, while up to 37 were measured for urban surface soils. All elements except Cd and U (both depths) and TiO_2 (surface soils) were log transformed to improve the fit of the data to a Gaussian distribution. The ANOVA calculations were performed using the NESTED procedure from the statistical software package, MINITAB^{TM}. The results of the ANOVA indicate that for most elements the between-site variability is greater than 80% of the total variance (Table 2). This suggests that geochemical variation is the principal control on element concentrations in urban areas. The between-site variance of Cd is significantly lower than the other elements, with nearly half the variation in the surface soils attributed to residual factors. This is an indication of analytical error, most likely to result from low overall concentrations with respect to the detection limit.

The ANOVA analysis was not carried out on Al_2O_3, CaO, K_2O, P_2O_5, SiO_2 or MgO, as these major elements were not analysed routinely in the urban sampling programme.

3.3.3 Standards

G-BASE internal reference standards were analysed within each batch of field samples in order to monitor analytical instrument performance, and to provide continuity of data between different analytical campaigns. Internal standards were assigned unique sample IDs and inserted into each batch of field samples. In the case of Scunthorpe, G-BASE internal reference standards S13 and S15 were analysed with the surface (A) and profile (S) soil samples. Each reference standard was analysed in duplicate, and mean concentrations for all elements in S13 and S15 are illustrated in Table 3.

The inclusion of G-BASE internal reference standards throughout all G-BASE and GSUE projects maintains data integrity between such projects. Scunthorpe lies within the Humber-Trent regional geochemical atlas area, and it is therefore essential that data for the urban centre of Scunthorpe are compatible with that of the surrounding rural dataset, of approximately 7000 soil sample sites (British Geological Survey, In Prep). A number of G-BASE standards, including S13 and S15, were routinely analysed with the Humber-Trent samples, the mean

element concentrations for these standards are compared with results for the Scunthorpe urban area in Table 3.

Where values differed significantly, the data were normalised using simple X-Y plots and regression calculations to correct for calibration variance between sample batches.

Table 2 ANOVA percentage of variance in surface and profile soils from 11 urban centres attributable to between-site, between-sample and residual variance

Surface Soils		Variance			Profile Soils		Variance		
Element	Number of Replicate Sets	Between Site (%)	Between Sample (%)	Residual (%)	Element	Number of Replicate Sets	Between Site (%)	Between Sample (%)	Residual (%)
Sb	16	88.03	1.15	10.82	Sb	50	87.68	3.05	9.27
As	37	97.69	2.02	0.29	As	50	97.87	1.82	0.31
Ba	37	97.63	1.79	0.58	Ba	50	97.39	2.56	0.05
Cd	27	47.88	6.77	45.35	Cd	50	65.44	3.95	30.61
Cr	37	94.14	3.07	2.79	Cr	50	93.46	5.55	0.99
Co	37	96.35	0.00	3.65	Co	50	94.00	5.62	0.38
Cu	37	97.63	1.66	0.72	Cu	50	98.87	1.08	0.06
Fe_2O_3	37	97.69	2.06	0.25	Fe_2O_3	50	96.62	3.36	0.01
Pb	27	97.48	2.23	0.29	Pb	50	96.51	3.43	0.06
MnO	37	98.28	1.39	0.33	MnO	50	96.03	3.92	0.05
Mo	33	94.24	0.71	5.05	Mo	50	93.59	3.23	3.17
Ni	37	98.06	1.59	0.34	Ni	50	95.96	3.83	0.21
Sn	36	93.45	2.91	3.63	Sn	50	95.77	2.42	1.81
TiO_2	37	96.58	2.65	0.77	TiO_2	-	-	-	-
U	37	85.95	1.24	12.81	U	47	76.92	10.99	12.09
V	37	97.89	1.79	0.32	V	50	97.85	2.09	0.06
Zn	37	94.77	5.16	0.07	Zn	50	92.64	7.34	0.02

Table 3 Comparison of results for G-BASE bulk soil standards

Sample Type	Units	Humber-Trent	Scunthorpe A	Scunthorpe S	Humber-Trent	Scunthorpe A	Scunthorpe S
Standard ID		S13	S13	S13	S15	S15	S15
Al_2O_3	wt%	-	17.9	-	-	6.35	-
Sb	mg/kg	0.1	<1	<1	1.1	<1	1.5
As	mg/kg	15	15	15	9	8	9
Ba	mg/kg	1704	1797	1924	291	378	380
Cd	mg/kg	<1	<1	<1	<1	<1	1
CaO	wt%	0.35	0.33	-	0.20	0.16	-
Cr	mg/kg	98	96	99	41	32	35
Co	mg/kg	29	22	24	9	5	7
Cu	mg/kg	17	15	16	6	3	4
Fe_2O_3	wt%	6.88	6.95	7.11	1.88	1.92	2.03
K_2O	wt%	2.2	2.2	-	2.3	2.1	-
Pb	mg/kg	109	109	111	24	25	24
MgO	wt%	1.2	1.1	-	0.6	0.5	-
MnO	wt%	0.128	0.107	0.120	0.082	0.059	0.069
Mo	mg/kg	1.6	1.7	1.1	0.7	1.1	0.9
Ni	mg/kg	36	36	36	12	10	11
P_2O_5	wt%	0.13	0.13	-	0.09	0.09	-
SiO_2	wt%	-	56.2	-	-	75.6	-
Sn	mg/kg	3	2	1	5	4	5
TiO_2	wt%	0.817	0.882	-	0.392	0.423	-
U	mg/kg	2.5	3.1	3.3	1.2	1.4	1.9
V	mg/kg	97	85	94	35	23	31
Zn	mg/kg	113	112	113	30	29	29

3.4 ANALYTICAL PROCEDURES

All samples were analysed at the BGS laboratories for a range of elements by Wavelength Dispersive X-Ray Fluorescence Spectrometry (XRFS) (Ingham and Vrebos, 1994). Three sequential XRF spectrometers were used. A Philips PW1480 fitted with a 216 position sample changer and a 3 kW/100 kV tungsten anode X-ray tube was used to determine Cd, Sn and Sb. Two Philips PW2400 spectrometers fitted with 102 position sample changers and with 3 kW/60 kV rhodium anode x-ray tubes were used to determine Al_2O_3, CaO, K_2O, MgO, P_2O_5, SiO_2, TiO_2, MnO, Fe_2O_3, V, Cr, Co, and Ba in one suite and Ni, Cu, Zn, As, Mo, Pb, and U in another.

The elements determined and the lower limits of detection (LLD) and upper reporting limits (URL) for each analyte are shown in Table 4.

The quoted LLDs are theoretical values for the concentration equivalent to three standard deviations above the background count rate for the analyte in a pure silica matrix. High instrumental stability results in practical values for these materials approaching the theoretical.

Table 4 Lower limits of detection (LLD) and upper reporting limit (URL) values for XRFS analysis of GSUE urban soil samples

Analyte	LLD (mg/kg)	LLD (%)	URL (mg/kg)	URL (%)
MnO	-	0.01	-	10.0
Fe_2O_3	-	0.01	-	100.0
V	2.4	-	20000	-
Cr	3	-	250000	-
Co	1.9	-	10000	-
Ni	0.9	-	4000	-
Cu	0.9	-	6500	-
Zn	1	-	10000	-
As	0.9	-	10000	-
Mo	0.5	-	1000	-
Cd	0.9	-	500	-
Sn	1.1	-	10000	-
Sb	1.2	-	10000	-
Ba	2.9	-	600000	-
Pb	1.2	-	10000	-
U	0.5	-	650	-
TiO_2*	-	0.01	-	100.0
SiO_2*	-	0.1	-	100.0
Al_2O_3*	-	0.1	-	100.0
P_2O_5*	-	0.05	-	1.5
K_2O*	-	0.05	-	15.0
CaO*	-	0.05	-	60.0
MgO	-	0.1	-	50.0

* A soils only.

3.5 DATA INTERPRETATION

Once full error control and data quality procedures were completed, the spatially registered Scunthorpe geochemical data were loaded into an Arcview© GIS software package. Graduated symbol geochemical maps for surface and profile soils categorised according to percentiles of the data distribution (Appendix B) were then generated (see Appendix C).

4 Geochemical Interpretation

4.1 BACKGROUND LEVELS

In order to aid the interpretation of the geochemical data for Scunthorpe, it is useful to be aware of typical background concentrations of elements in the surrounding rural environment to place the urban data in context. Rural soil geochemical data generated by the G-BASE programme are available for the Humber-Trent region, in which Scunthorpe is located. The median elemental concentrations for approximately 6561 surface soil samples are shown in Table 5 and the concentrations for approximately 6877 profile soils are displayed in Table 6. These data can be used to give an indication of the typical magnitude of elemental concentrations throughout the Humber-Trent region.

The median value of a soil dataset provides an indication of the typical concentrations for elements across the area, removing the influence of outliers caused by isolated regions of contamination. However, it should be noted that background values in the urban environment, as well as the rural environment (to a lesser extent), are likely to be influenced to some degree by diffuse pollution.

In the Scunthorpe surface soils, median concentrations of the elements Sb, As, Pb, MnO, V and Zn are above the regional median, whilst As, Cd, Cr, Co, Cu, Fe_2O_3, MnO, Mo, Ni, Pb, V and Zn are above the regional median in the profile soils, although the differences are generally very small. Interestingly, the median concentration of Fe_2O_3 is lower in the surface soils of Scunthorpe than across the Humber-Trent region, despite the location of Scunthorpe over the Frodingham Ironstone, and the associated steel-making industry within the town. Elevated levels of Fe and Mn occur in soils overlying several parent material types across the Humber-Trent region (for example, the Carboniferous Coal Measures and the Jurassic and Cretaceous Ironstone formations), thus raising the regional median values for these elements (British Geological Survey, In Prep).

Table 5 Comparison of median concentrations in regional surface soil samples from the Humber-Trent atlas area (6561 samples) with Scunthorpe urban surface soil samples (196 samples)

Analyte	Units	Median Regional	Median Scunthorpe
Al_2O_3	wt%	11.5	6
Sb	mg/kg	0.5	1
As	mg/kg	13	19
Ba	mg/kg	376	278
Cd	mg/kg	1	1
CaO	wt%	2.12	0.95
Cr	mg/kg	71	55
Co	mg/kg	19	15
Cu	mg/kg	18	15
Fe_2O_3	wt%	4.66	4.63
Pb	mg/kg	43	45
MgO	wt%	1.1	0.5
MnO	wt%	0.080	0.103
Mo	mg/kg	2.2	1.6
Ni	mg/kg	22	15
K_2O	wt%	-	1.28
P_2O_5	wt%	0.29	0.26
SiO_2	wt%	-	63.1
Sn	mg/kg	4	4
TiO_2	wt%	0.680	0.268
U	mg/kg	2.1	1.2
V	mg/kg	83	86
Zn	mg/kg	72	79

Table 6 Comparison of median concentrations in regional profile soil samples from the Humber-Trent atlas area (6877 samples) with Scunthorpe urban profile soil samples (192 samples)

Analyte	Units	Median Regional	Median Scunthorpe
Al_2O_3	wt%	-	-
Sb	mg/kg	3	1
As	mg/kg	12	26
Ba	mg/kg	388	355
Cd	mg/kg	0.35	1
CaO	wt%	2.89	-
Cr	mg/kg	83	93
Co	mg/kg	21	23
Cu	mg/kg	20	22
Fe_2O_3	wt%	5.04	6.65
Pb	mg/kg	38	54
MgO	wt%	1.3	-
MnO	wt%	0.104	0.136
Mo	mg/kg	1.8	2.0
Ni	mg/kg	27	28
K_2O	wt%	1.98	-
P_2O_5	wt%	0.25	-
SiO_2	wt%	-	-
Sn	mg/kg	4	4
TiO_2	wt%	0.735	-
U	mg/kg	2.5	1.9
V	mg/kg	88	125
Zn	mg/kg	77	97

4.2 GEOCHEMICAL VARIATION WITH DEPTH

In a comparison of surface and profile soils, it should again be noted that during sample preparation the two sample types are sieved to different size fractions. The surface soils are sieved to <2 mm whilst the profile soils are sieved to <150 µm. This means that the sieved profile soil has a much larger surface area and will contain more clay particles (which possess the ability to attract and bind many metallic elements (Brady and Weil, 1999)) and this may affect the geochemical results.

A total of 23 major and trace elements were measured in Scunthorpe top-soils; aluminium (expressed as Al_2O_3), antimony (Sb), arsenic (As), barium (Ba), calcium (expressed as CaO), cadmium (Cd), chromium (Cr), cobalt (Co), copper (Cu), iron (expressed as Fe_2O_3), lead (Pb), magnesium (expressed as MgO), manganese (expressed as MnO), molybdenum (Mo), nickel (Ni), phosphorus (expressed as P_2O_5), potassium (expressed as K_2O), silicon (SiO_2), tin (Sn), titanium (expressed as TiO_2), uranium (U), vanadium (V) and zinc (Zn). All elements except Al_2O_3, CaO, MgO, K_2O, P_2O_5, SiO_2 and TiO_2 were additionally measured in the profile soils.

A number of elements have higher median concentrations in the profile soils of Scunthorpe, than in the surface soils (As, Ba, Cr, Co, Cu, Fe_2O_3, Pb, MnO, Mo, Ni, U, V and Zn) (Tables 5 and 6). There are several scenarios that could account for this situation. For example, aerially deposited and surface derived anthropogenic contamination may be transported through the soil profile over time, although higher concentrations would nevertheless be expected in the surface soils in this situation. Elevated concentrations of elements within deeper soils may also reflect a strong geogenic influence; for example, where surface soils have become depleted in major and trace elements due to weathering processes, whilst deeper soils are more enriched in weathered rock minerals. It is also possible that less-contaminated surface soils may have developed over older areas of made ground, resulting in lower concentrations of some elements in the surface soils. However, in the case of Scunthorpe, the differences between the soil depths are most likely to reflect the fact that many of these elements are concentrated within the finer soil fractions, leading to higher values in the more finely-sieved profile soils. Most of the elements listed (As, Ba, Cr, Co, Cu, Fe_2O_3, Pb, MnO, Mo, Ni, U, V and Zn) are not significantly elevated above the regional median values and some in fact have lower median values in the surface and profile soils (Tables 5 and 6). They may, therefore, not be significant contaminants in Scunthorpe.

4.3 GEOCHEMICAL DISTRIBUTION IN SURFACE SOILS

The maps in Appendix C demonstrate that major and trace element concentrations are generally higher over the Frodingham Ironstone Formation, through the central part of the sample area, than over other parent materials (largely blown sand) underlying the western, northeast and southeast margins of the sample grid (Figures 4 and 5). This is to be expected as ironstones typically contain high concentrations of many metal elements relative to other rock types. Indeed evidence from the study area, based on the analysis of twelve rock samples of Frodingham Ironstone by BGS (Palumbo-Roe *et al.*, 2005) demonstrate that this parent material is enriched in a number of major and trace elements, especially Fe_2O_3, CaO, As, V, Ni, Cr and Co (Table 7). The samples were collected from a range of depths through the ironstone sequence (total depth approx. 8 m), in two locations at Conesby Quarry to the north of Scunthorpe (Approximate BNG reference: 899000E, 141000N).

4.3.1 Major elements

Of all the determinands, SiO_2 is the only one to be clearly present in lower concentrations in samples collected over the Frodingham Ironstone, than over the surrounding blown sand deposits (Appendix C). Soils overlying blown sand largely contain over 60% SiO_2, which can be attributed to quartz-rich sand derived from the parent material.

The possible influence of anthropogenic contamination on major element concentrations in the surface soils is most apparent in the distributions of Fe_2O_3 and MnO. Concentrations of these elements are elevated in the region of the steel workings to the east and northeast of the urban area (with maximum values of 34 % and 1.3 %, respectively) (Appendix C) and probably relate to the excavation and processing of the ironstone at the works. High levels of CaO, MgO and P_2O_5 in soils in the north-east and east of the city may also be associated with the steel workings in Scunthorpe.

4.3.2 Trace elements

Relatively high concentrations of the trace elements As, Cr, Cu, Pb, Mo, Ni, Sn, V and Zn occur in the surface soils in the northeast of the urban area and extend further into the northern and eastern parts of the sampling area (Appendix C). This may again be associated with the steel-making industry in the vicinity (section 2.2) and the related railway lines and made ground. The latter is likely to contain ash and slag from the steelworks operations.

Concentrations of Pb and Ba are more significantly elevated in surface soils within the city centre of Scunthorpe, than in the industrial areas to the north and east. This may be related to traffic density and the presence of Ba and Pb in petroleum products. Prior to 2000, tetra-ethyl Pb was added to petrol as an anti-knocking agent. Barium has been identified as a possible alternative tracer to Pb for vehicle emissions in surface soils as it can be found in petrol, as well as in unleaded petrol and diesel oil (Monaci and Bargagli, 1997). A number of other trace elements are also found as impurities in petroleum products and can influence urban geochemical signatures. Many other major and trace elements are generally elevated in concentration in soils within the city centre with respect to the surrounding outskirts to the north, south and west. Tin is particularly high in concentration (>25 mg/kg) in the east of the city centre, where the A1029 crosses the main railway line (Figure 2), coinciding with high levels of elements such as Ba and Zn. Transport and industry are likely to contribute significantly to the levels of many trace elements within soils in the Scunthorpe urban area.

The ranges in concentration for Sb and Cd in the surface soils are very small and it is therefore difficult to interpret any significant patterns. The highest levels of Sb are generally concentrated within the urban area and may therefore be influenced by contamination, while Cd levels appear to be relatively evenly distributed, with the exception of 3 isolated higher values (Appendix C).

4.4 GEOCHEMICAL DISTRIBUTION IN PROFILE SOILS

The concentrations of the majority of trace elements analysed (As, Ba, Cr, Co, Mo, Ni, U and V) are higher in the profile soils, than in the surface soils, across the whole distribution range. This is likely to be related to the difference in size fraction analysed (see section 4.2). Concentrations of Pb in the profile soils are slightly less than those of the surface soils in the lower ranges of the distribution, but are higher from the 50^{th} percentile upwards, with respect to the surface soil concentrations (Appendix B). The distribution of Cd is more variable in the profile soils than in the surface soils, which may again be related to concentration of this element in the finer soil fractions (Appendix C). The highest levels of Cd (3-30 mg/kg) are scattered across the sampling area, although there is possibly some relationship with transport routes, especially to the north of Scunthorpe. Antimony also shows greater dispersion of high concentrations in profile than surface soils again probably related to the finer size fraction of the deeper soils. In the case of all other elements analysed at both sample depths, the distributions are generally very similar in the surface and profile soils (Appendix C).

4.5 SOIL GEOCHEMISTRY OF SCUNTHORPE IN RELATION TO OTHER HUMBER-TRENT URBAN AREAS

The results for selected elements from surface soils in Scunthorpe are presented in Figure 7 in the context of six other urban areas from the Humber-Trent region (Doncaster, Hull, Lincoln, Mansfield, Sheffield and York) and the results from the rural survey of the Humber-Trent region. Eight elements that may be affected by anthropogenic contamination in urban areas (Sb, As, Cd, Cu, Pb, Mo, Sn and Zn) are presented, as well as TiO_2 as a representative conservative element, unaffected by contamination.

Concentrations of TiO_2 are normally distributed in each urban area and fall within the range in concentration found on the regional scale as expected. In contrast, distributions of the other selected elements are in general positively skewed (indicated by a mean value significantly exceeding the median) in all the datasets and urban concentrations are higher than the regional values. These results indicate the degree of contamination in the urban environments as a result of anthropogenic contamination relative to the rural background.

In terms of the regional Humber Trent data, recent work carried out by the BGS (Rawlins *et al.*, 2003) has demonstrated the importance of parent material type in determining the geochemical composition of soils. The main controls over variation in concentrations between different urban areas may therefore include parent material type, although population and past and present industrial activities are likely to be more important.

Soil Guideline Values (SGV) produced by the Contaminated Land Exposure Assessment (CLEA) model (Department of the Environment Food and Rural Affairs and the Environment Agency, 2002a; Department of the Environment Food and Rural Affairs and the Environment Agency, 2002b) for residential areas with plant uptake are shown on Figure 7 for Cd and As. Cadmium is present in concentrations of 1 mg/kg or less in over 75 % of the surface soil samples collected in Scunthorpe, below the SGV for this element. The values are relatively low compared to other urban areas in the Humber-Trent region, some of which exceed the SGV for low-pH soils in a number of samples. The concentrations of As in Scunthorpe are relatively high, compared to most other urban areas in the region, with almost half the samples exceeding the 20 mg/kg SGV for residential land use. However, as indicated in section 4.3 of this report, the source of the As in Scunthorpe is likely to be largely natural related to the ironstone underlying the city. The XRFS analysis of twelve rock samples of Frodingham Ironstone from the area demonstrates an enrichment of As within this parent material, with a median concentration of 82 mg/kg and a mean concentration of 119 mg/kg (Table 7) (Palumbo-Roe *et al.*, 2005). In contrast, mean values of As in most igneous and sedimentary rocks are commonly in the region of 2 mg/kg (O'Neill, 1995). It is likely, therefore, that As is transferred from the ironstone to the soil, by weathering processes (as well as from mining and steelmaking operations). This is supported by the distribution pattern, with elevated values in soils overlying the Frodingham Ironstone (section 4.3.2).

Median soil concentrations of As are at or above 20 mg/kg in Kingston-upon-Hull and Sheffield, which for these cities probably reflects industrial and urban rather than natural sources (Figure 7). It is interesting to note that the Humber-Trent regional soil median is above 10 mg/kg, suggesting that levels of As may be naturally enriched due to the presence of As-rich parent materials such as ironstones and coals in the area.

The six other potential contaminants selected in Figure 7 (Sb, Cu, Pb, Mo, Sn and Zn) do not appear to be elevated in the Scunthorpe surface soils, with respect to other Humber-Trent urban areas, and the ranges are generally very similar to the concentrations observed in the Humber-Trent regional dataset. This suggests that these elements are not significant contaminants in the Scunthorpe area. Although Zn demonstrates elevated concentrations towards the upper ranges of the distribution, the levels are lower than those found in Kingston-upon-Hull, Sheffield, Mansfield and Doncaster. Table 7 indicates that Zn is the only element, of these six potential contaminants, to be present in elevated concentrations within the Frodingham Ironstone parent

material underlying Scunthorpe, with a median value of 125 mg/kg in twelve samples. The higher levels of Zn within the upper ranges of the distribution may therefore be related to processing of ironstone within the steelmaking industry, as suggested in section 4.3.2.

Table 7 Geochemical analysis by XRFS of twelve rock samples of Frodingham Ironstone, from Conesby Quarry, Scunthorpe (Palumbo-Roe *et al.*, 2005)

Sample	Al_2O_3	As	Ba	CaO	Cr	Co	Cu	Fe_2O_3	Pb	MnO	Mo	Ni	K_2O	P_2O_5	SiO_2	TiO_2	U	V	Zn
Number	**%**	**mg/kg**	**mg/kg**	**%**	**mg/kg**	**mg/kg**	**mg/kg**	**%**	**mg/kg**	**%**	**mg/kg**	**mg/kg**	**%**	**%**	**%**	**%**	**mg/kg**	**mg/kg**	**mg/kg**
SC1	3.1	114	16	22.10	145	40	4	34.18	48	1.06	4	100	0.12	0.38	3.7	<0.100	<1	637	308
SC2	3.2	81	71	27.95	104	42	3	24.10	38	1.28	4	102	0.23	1.28	4.5	0.129	3	468	95
SC3	1.3	37	13	31.69	27	16	<1	17.56	43	1.58	2	31	<0.10	0.42	1.7	<0.100	2	328	110
SC4	3.8	100	34	18.74	97	45	5	37.72	64	1.17	4	92	0.21	1.01	5.8	0.132	2	717	185
SC5	7.7	71	51	8.06	96	32	3	>40.00	43	1.75	4	85	0.55	1.11	13.6	0.239	<1	491	131
SC6	3.6	400	26	14.14	124	58	4	38.69	59	2.75	2	140	0.10	0.28	6.3	<0.100	<1	710	119
SC7	2.0	78	13	26.52	88	28	<1	23.95	36	1.47	4	67	<0.10	0.68	2.4	<0.100	<1	445	93
SC8	1.7	48	13	26.70	66	28	5	21.62	39	2.39	3	62	<0.10	0.26	2.3	<0.100	<1	351	182
SC9	2.5	83	19	26.11	66	33	<1	26.19	59	0.97	4	58	<0.10	0.55	3.4	<0.100	2	771	163
SC10	5.2	80	95	27.81	52	50	12	17.97	22	0.66	3	100	0.47	>2.00	10.3	0.193	18	276	59
SC11	2.9	97	34	24.30	98	47	4	25.37	43	1.75	2	110	0.13	0.78	4.8	0.100	<1	553	112
SC12	11.4	234	210	9.22	177	59	15	25.47	60	1.04	3	130	1.36	0.32	31.0	0.493	<1	700	209
mean	4	119	50	22	95	40	6	27	46	1	3	90	0	1	7	0	5	537	147
median	3.2	82	30	25.2	96.5	41	4	25.4	43	1.4	3.5	96	0.2	0.6	4.7	0.2	2.0	522	125

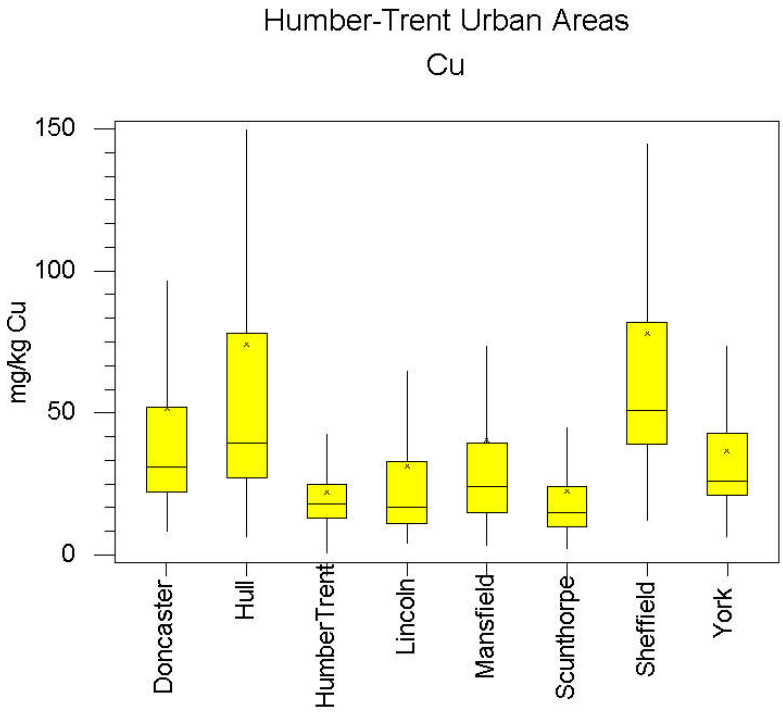


Figure 7: (a) Copper in surface soil

Figure 7 (*(a)* - *(i)*) Box and Whisker Plots of the 5th, 25th, 50th, 75th and 95th percentiles of selected element concentrations in surface soils from seven urban areas in the Humber-Trent region presented with the regional Humber-Trent data. Soil Guideline Values (SGVs) for soils in residential areas involving plant uptake (derived using the CLEA model) are shown in red for As and Cd. Note that for Pb (450 mg/kg) and Cd (pH = 8, 8 mg/kg) SGV values are outside plot area. x = mean value.-

SGV = (Department of the Environment Food and Rural Affairs and the Environment Agency, 2002b)

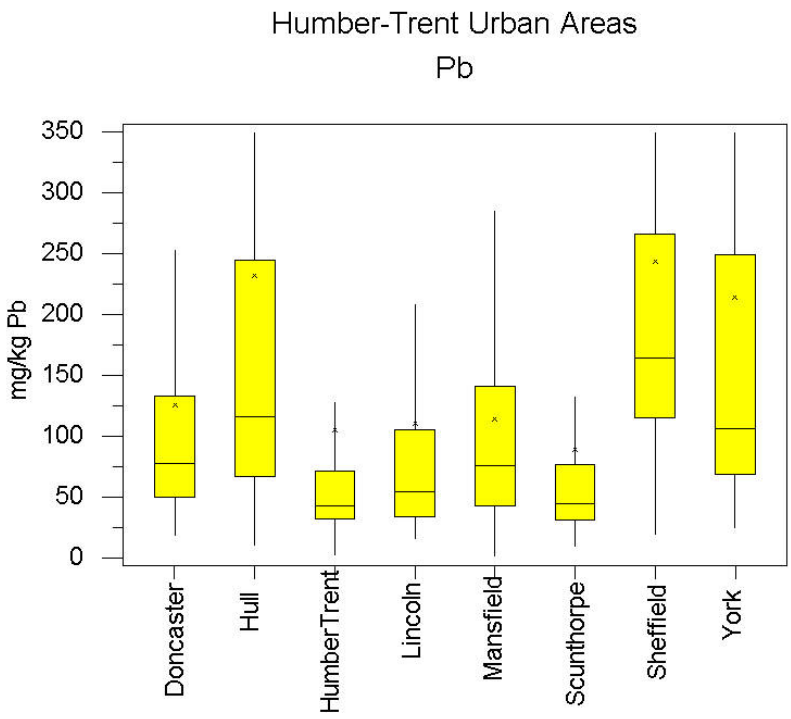


Figure 7: (b) Lead in surface soil

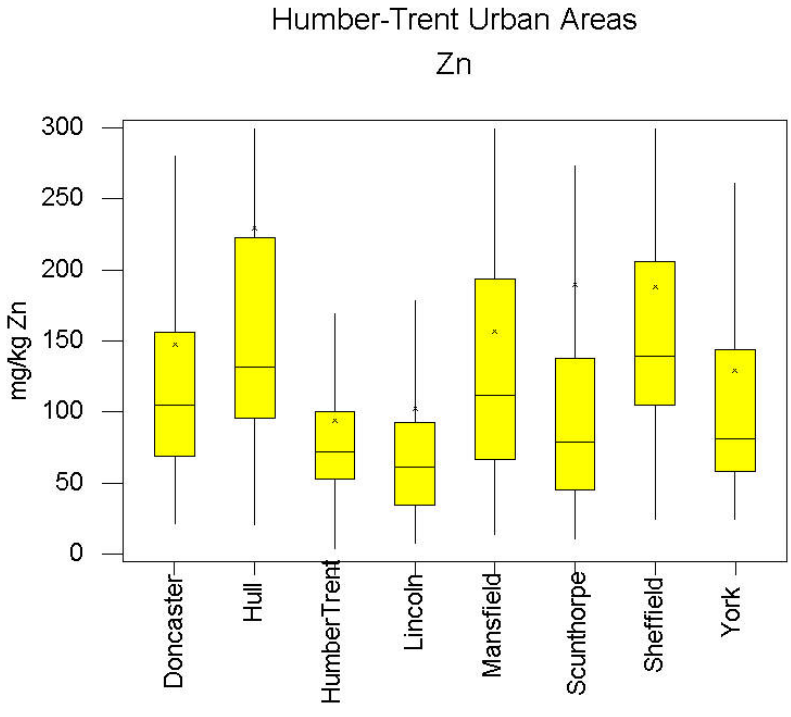


Figure 7: (c) Zinc in surface soil

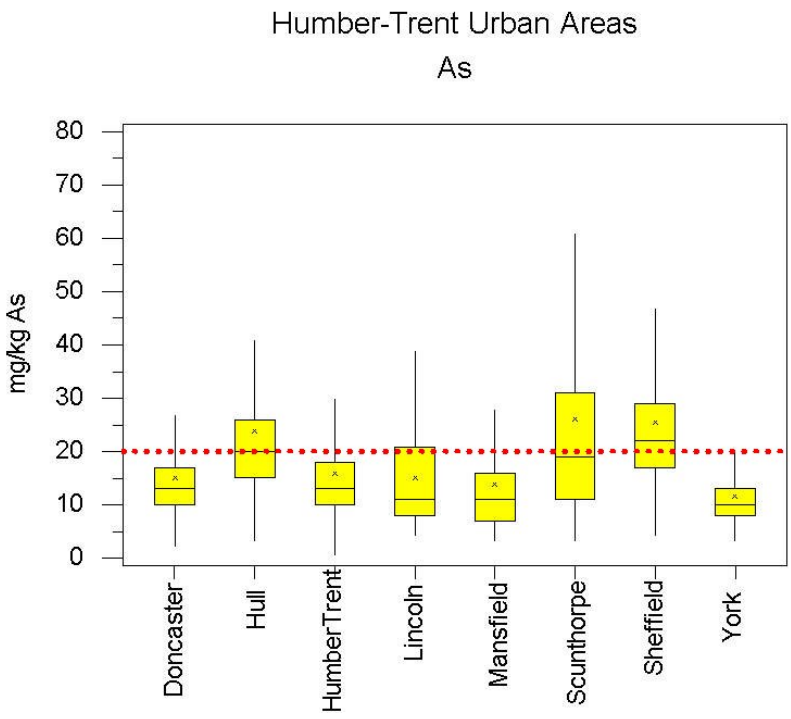


Figure 7: (d) Arsenic in surface soil

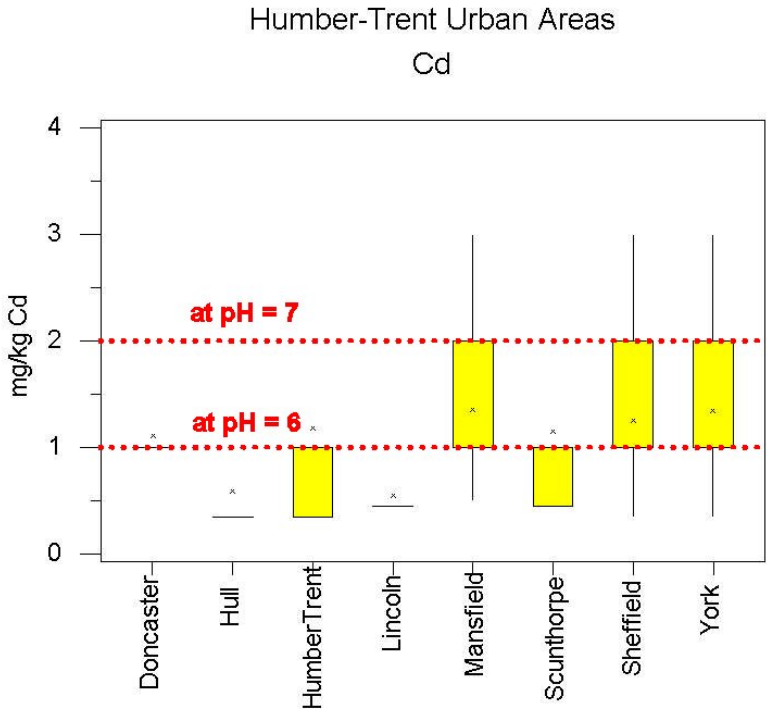


Figure 7: (e) Cadmium in surface soil

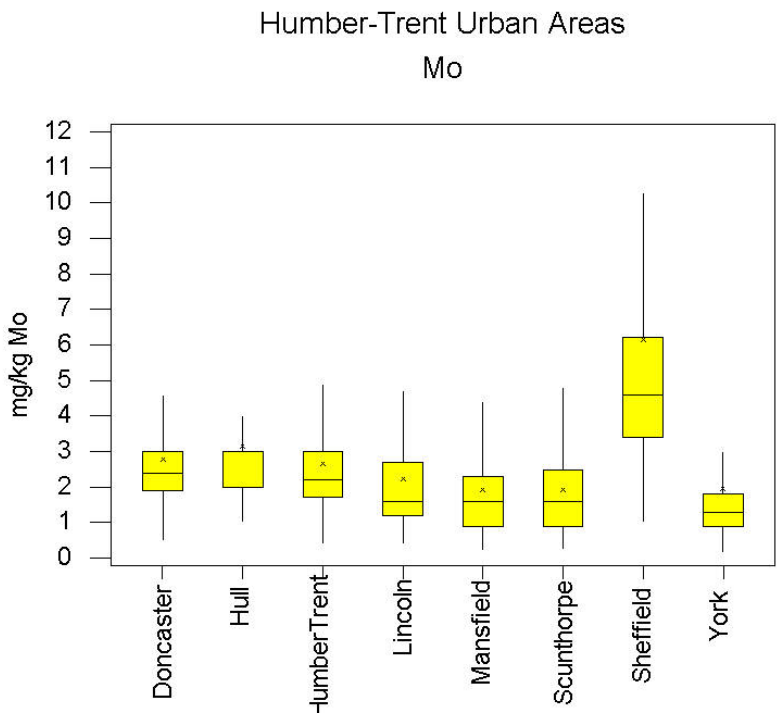


Figure 7: (f) Molybdenum in surface soil

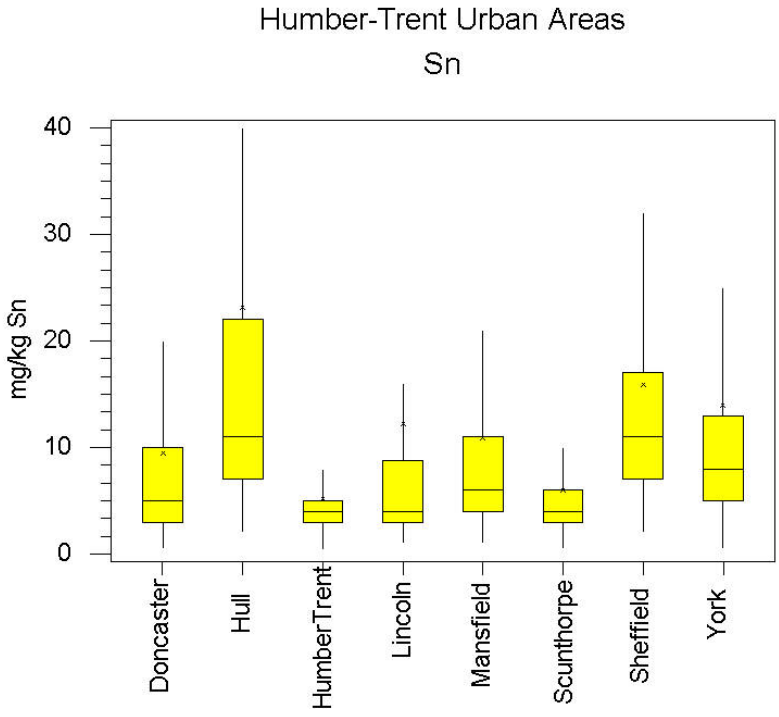


Figure 7: (g) Tin in surface soil

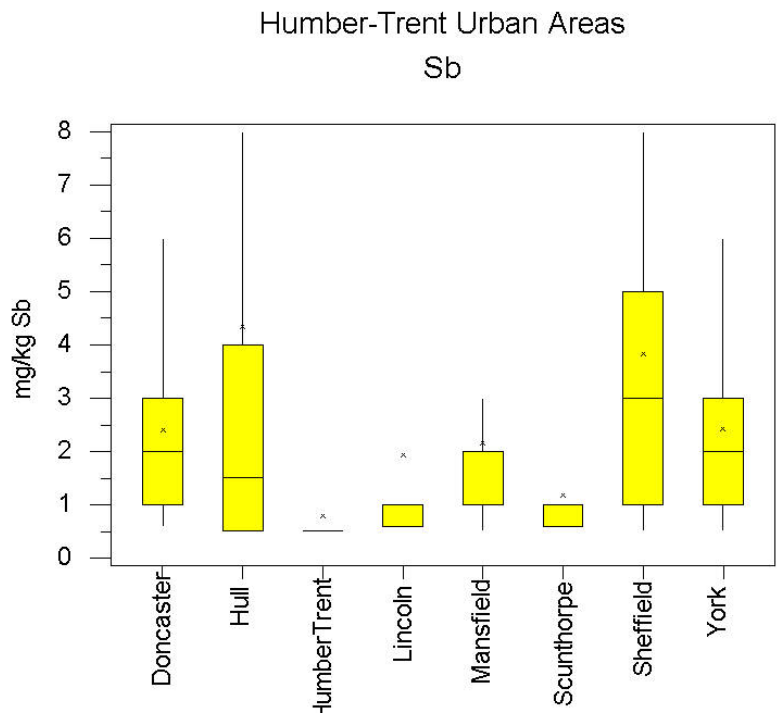


Figure 7: (h) Antimony in surface soil

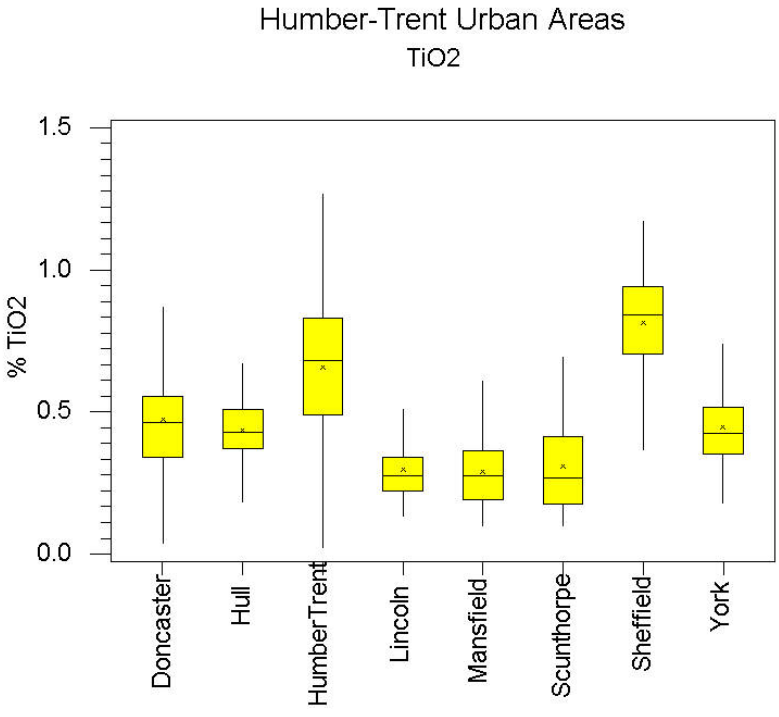


Figure 7: (i) Titanium oxide in surface soil

References

BRADY, N C and WEIL, R R. 1999. *The Nature and Properties of Soils.* (New Jersey: Prentice Hall.)

BRITISH GEOLOGICAL SURVEY. In Prep. *Regional Geochemistry of the Humber-Trent Region*. (Keyworth: British Geological Survey.)

DEPARTMENT OF THE ENVIRONMENT FOOD AND RURAL AFFAIRS AND THE ENVIRONMENT AGENCY. 2002a. *The Contaminated Land Exposure Assessment (CLEA) Model: Technical Basis and algorithms*. R&D Publication CLR 10 (Bristol: Environment Agency.)

DEPARTMENT OF THE ENVIRONMENT FOOD AND RURAL AFFAIRS AND THE ENVIRONMENT AGENCY. 2002b. *Assessment of Risks to Human Health from Land Contamination: An Overview of the Development of Soil Guideline Values and Related Research*. R&D Publication CLR 7 (Bristol: Environment Agency.)

GOLDRING, D C. 1974. British Iron Ores: Their Future Use. *Proceedings of the Royal Society of London. A*, Vol. 339, 313-328.

HARRIS, J R and COATS, J S. 1992. *Geochemistry Database: Data Analysis and Proposed Design.* Mineral Reconnaissance Programme. Technical Report WF/92/5 (Keyworth: British Geological Survey.)

HODGE, C A H, BURTON, R G O, CORBETT, W M, EVANS, R and SEALE, R S. 1984. *Soils and Their Use in Eastern England*. Bulletin No. 13. (Harpenden: Soil Survey of England and Wales.)

INGHAM, M N and VREBOS, B A R. 1994. High productivity geochemical XRF analysis. *Advances in X-ray Analysis*, Vol. 37, 717-724.

INSTITUTE OF GEOLOGICAL SCIENCES. 1982. *Brigg, Sheet 89. Solid Edition.* (Southampton: Ordnance Survey.)

INSTITUTE OF GEOLOGICAL SCIENCES. 1983. *Kingston-upon-Hull, Sheet 80. Solid Edition.* (Southampton: Ordnance Survey.)

JOHNSON, C C, and BREWARD, N. 2004. *G-BASE Geochemical Baseline Survey of the Environment.* Commissioned Report, CR/04/016N. (Keyworth: British Geological Survey.)

JOHNSON, C C, BROWN, S E, and LISTER, T R. 2003. *G-BASE Field Procedures Manual version 1.1.* Internal Report No. IR/03/096N. (Keyworth: British Geological Survey)

LISTER, T R. 2002. *Analysis of Variance (ANOVA) of G-BASE Sub-Surface Soil Data from 11 Urban Centres in England and Wales*. Internal Report, IR/02/009. (Keyworth: British Geological Survey.)

LISTER, T R. In Prep. *Analysis of Variance (ANOVA) of G-BASE Surface Soil Data from 11 Urban Centres in England and Wales*. Internal Report. (Keyworth: British Geological Survey.)

MONACI, F and BARGAGLI, R. 1997. Barium and other trace metals as indicators of vehicle emissions. *Water Air and Soil Pollution*, Vol. 100, 89-98.

O'NEILL, P. 1995. Arsenic. In *Heavy Metals in Soils* (second edition). ALLOWAY, B J (editor). (Glasgow: Blackie Academic and Professional). 105-119.

PALUMBO-ROE, B, CAVE, M R, KLINCK, B A, WRAGG, J, TAYLOR, H, O'DONNELL, K E and SHAW, R A. 2005. Bioaccessibility of arsenic in soils developed over Jurassic Ironstones in eastern England. *Environmental Geochemistry and Health*, In Press.

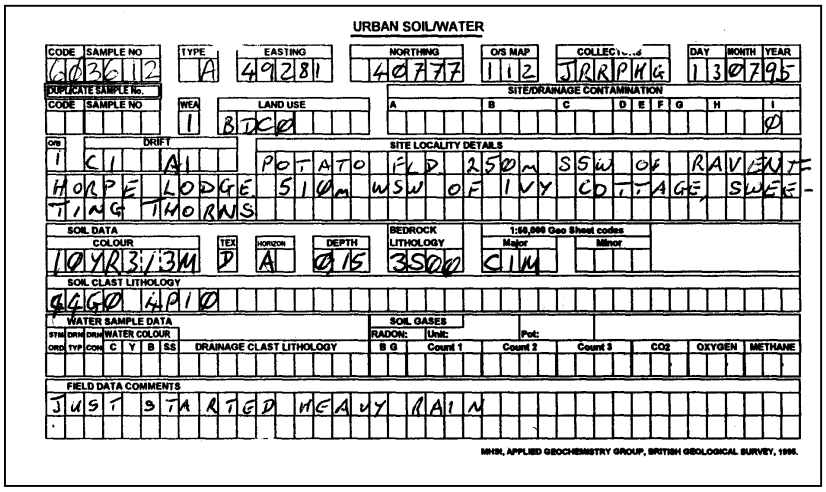
PLANT, J A. 1973. A random numbering system for geochemical samples. *Transactions of the Institution of Mining and Metallurgy (Section B: Applied Earth Science)*, Vol. 82, B63-B66.

PLANT, J A, JEFFREY, K, GILL, E, and FAGE, C. 1975. The systematic determination of error, accuracy and precision in geochemical exploration data. *Journal of Geochemical Exploration*, Vol. 4, 467-486.

RAWLINS, B G, WEBSTER, R and LISTER, T R. 2003. The influence of parent material on top soil geochemistry in eastern England. *Earth Surface Processes and Landforms*, Vol. 28, 1389-1409.

SLATER, D and HIGHLEY, D E. 1976. The iron ore deposits in the United Kingdom of Great Britain and Northern Ireland. *The Iron Ore Deposits of Europe and adjacent Areas*, Vol. 1, 393-409.
SNEDECOR, G W and COCHRAN, W G. 1989. *Statistical Methods* (8th edition). (Ames, Iowa, USA: Iowa State University Press.)
SOIL SURVEY OF ENGLAND AND WALES. 1983. *Sheet 4, Soils of Eastern England. 1:250 000*. (Southampton: Ordnance Survey.)
WHITEHEAD, T H, ANDERSON, W, WILSON, V and WRAY, D A. 1952. *The Liassic Ironstones*. Memoirs of the Geological Survey of Great Britain. (London: Her Majesty's Stationery Office.)
YOUNG, T. 1993. Sedimentary Iron Ores. In *Mineralization in the British Isles*. PATTRICK, R A D and POLYA, D A (editors). (London: Chapman & Hall). 446-489.

Appendix A: Examples of urban surface and profile soil field cards from Scunthorpe.



URBAN SOIL/WATER

CODE	SAMPLE NO	TYPE	EASTING	NORTHING	O/S MAP	COLLECTOR	DAY	MONTH	YEAR
60	36112	A	492881	407477	112	JRRPHG	13	07	95

DUPLICATE SAMPLE No.

CODE	SAMPLE NO	WEA	LAND USE	SITE/DRAINAGE CONTAMINATION A	B	C	D	E	F	G	H	I
		1	BDCØ									Ø

O/B	DRIFT	SITE LOCALITY DETAILS
1	CI AI	POTATO FLD 250m SSW OF RAVENT-HORPE LODGE 510m WSW OF IVY COTTAGE, SWEE-TING THORNS

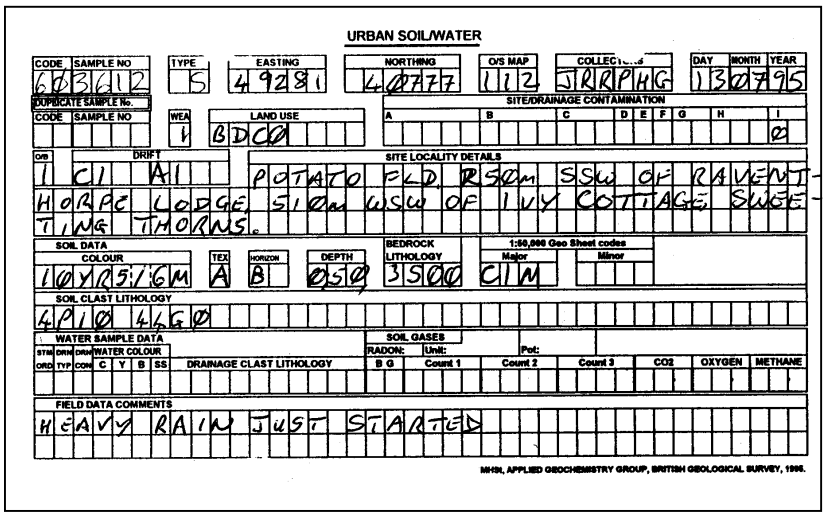
SOIL DATA COLOUR	TEX	HORIZON	DEPTH	BEDROCK LITHOLOGY	1:50,000 Geo Sheet codes Major	Minor
10YR3/3M	D	A	Ø15	3500	CIM	

SOIL CLAST LITHOLOGY: 4G GØ 4P1Ø

WATER SAMPLE DATA STM DRN DRN WATER COLOUR ORD TYP CON C Y B SS DRAINAGE CLAST LITHOLOGY	SOIL GASES RADON: Unit: Pot: B G	Count 1	Count 2	Count 3	CO2	OXYGEN	METHANE

FIELD DATA COMMENTS: JUST STARTED HEAVY RAIN

MHSN, APPLIED GEOCHEMISTRY GROUP, BRITISH GEOLOGICAL SURVEY, 1995.



URBAN SOIL/WATER

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		1	BDCØ									Ø

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1	CI AI	POTATO FLD. 250m SSW OF RAVENT-HORPE LODGE 510m WSW OF IVY COTTAGE SWEE-TING THORNS.

SOIL DATA COLOUR	TEX	HORIZON	DEPTH	BEDROCK LITHOLOGY	1:50,000 Geo Sheet codes Major	Minor
10YR5/6M	A	B	Ø50	3500	CIM	

SOIL CLAST LITHOLOGY: 4P1Ø 4G GØ

WATER SAMPLE DATA STM DRN DRN WATER COLOUR ORD TYP CON C Y B SS DRAINAGE CLAST LITHOLOGY	SOIL GASES RADON: Unit: Pot: B G	Count 1	Count 2	Count 3	CO2	OXYGEN	METHANE

FIELD DATA COMMENTS: HEAVY RAIN JUST STARTED

MHSN, APPLIED GEOCHEMISTRY GROUP, BRITISH GEOLOGICAL SURVEY, 1995.

Appendix B: Percentile calculations for Scunthorpe soils

A-Soils:	MgO	SiO_2	Al_2O_3	P_2O_5	K_2O	CaO	TiO_2	MnO	Fe_2O_3	V	Cr	Co	Ni	Cu	Zn	As	Mo	Ba	Pb	U	Cd	Sn	Sb
Percentile	**wt %**	**wt %**	**wt %**	**wt %**	**wt %**	**wt %**	**wt %**	**wt %**	**wt %**	**mg/kg**	**mg/kg**	**mg/kg**	**mg/kg**	**mg/kg**	**mg/kg**	**mg/kg**	**mg/kg**	**mg/kg**	**mg/kg**	**mg/kg**	**mg/kg**	**mg/kg**	**mg/kg**
99th	1.7	80.1	17.0	0.90	2.67	11.916	0.788	0.796	26.83	493	237	39	104	114	1707	146	6.4	552	542	2.92	4	25	6
95th	1.3	75.7	11.7	0.64	1.81	8.219	0.572	0.401	15.70	268	159	32	52	52	404	73	3.6	413	219	2.1	2	15	3
90th	1.0	73.3	10.2	0.54	1.66	5.492	0.535	0.268	10.60	197	107	29	41	39	230	46	3.2	373	149	2.0	2	10	2
75th	0.7	68.2	8.4	0.40	1.46	2.340	0.411	0.179	7.46	138	78	22	27	24	138	31	2.4	319	76	1.6	1	6	1
50th	0.5	63.1	6.0	0.26	1.28	0.950	0.268	0.103	4.63	86	55	15	15	15	79	19	1.6	278	45	1.2	1	4	1
25th	0.3	55.2	4.4	0.19	1.18	0.449	0.177	0.070	2.82	53	32	9	8	10	45	11	0.9	245	31	0.8	0.45	3	0.6
15th	0.2	51.1	3.9	0.17	1.11	0.326	0.156	0.057	2.27	42	26	8	6	8	34	9	0.7	231	25	0.7	0.45	3	0.6
10th	0.2	48.3	3.6	0.16	1.05	0.244	0.143	0.052	1.86	39	22	6	5	6	29	8	0.6	218	21	0.6	0.45	2	0.6
5th	0.2	43.0	3.0	0.14	0.99	0.190	0.125	0.038	1.23	30	16	5	4	5	22	6	0.4	205	19	0.4	0.45	2	0.6
Maximum	1.9	81.0	20.2	1.21	3.01	14.969	0.975	1.288	34.35	646	1108	51	202	433	10800	190	26.1	611	3300	3.9	28	130	19
Minimum	0.1	17.2	2.2	0.03	0.68	0.110	0.098	0.032	0.71	21	7	3	1	2	10	3	0.25*	165	9	0.25*	0.45*	0.5*	0.6*
Median	0.5	63.1	6.0	0.26	1.28	0.950	0.268	0.103	4.63	86	55	15	15	15	79	19	1.6	278	45	1.2	1	4	1
Mean	0.6	61.1	6.7	0.31	1.35	2.041	0.309	0.151	5.97	110	67	16	21	22	190	26	1.9	290	89	1.2	1	6	1

* minimum value reported as half detection limit

Appendix B: Percentile calculations for Scunthorpe soils

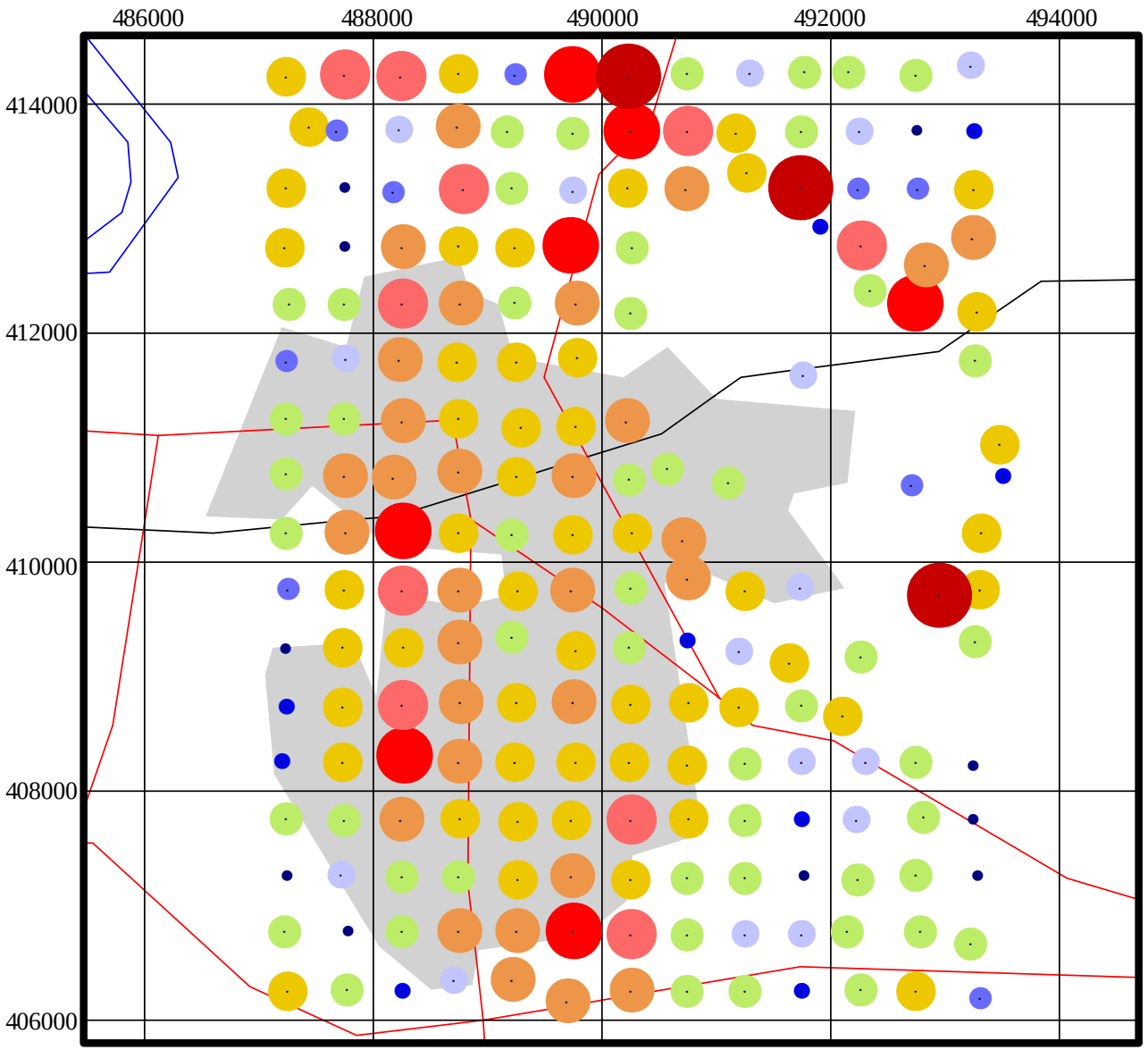
S-Soils:	MnO	Fe_2O_3	V	Cr	Co	Ba	Ni	Cu	Zn	As	Mo	Pb	U	Cd	Sn	Sb
Percentile	**wt %**	**wt %**	**mg/kg**	**mg/kg**	**mg/kg**	**mg/kg**	**mg/kg**	**mg/kg**	**mg/kg**	**mg/kg**	**mg/kg**	**mg/kg**	**mg/kg**	**mg/kg**	**mg/kg**	**mg/kg**
99th	1.193	34.00	604	508	51	746	129	217	1534	233	9.1	650	3.4	5.09	48	8
95th	0.675	20.40	344	162	40	525	74	66	512	119	4.3	259	2.9	3.00	17	3
90th	0.462	15.85	273	142	37	483	62	47	313	78	3.7	182	2.7	3.00	10	3
75th	0.241	10.08	188	116	31	414	45	28	167	49	2.6	99	2.3	2.00	6	2
50th	0.136	6.65	125	93	23	355	28	22	97	26	2.0	54	1.9	1.00	4	1
25th	0.072	4.38	71	64	13	315	15	13	65	17	1.5	34	1.4	0.45	3	0.6
15th	0.039	3.17	56	50	9	296	11	10	49	14	1.2	24	1.0	0.45	2	0.6
10th	0.028	2.18	42	41	7	283	9	8	35	11	1.1	20	0.9	0.45	2	0.6
5th	0.018	1.22	31	34	4	266	5	5	18	6	1.0	17	0.7	0.45	1	0.6
Maximum	2.040	36.35	686	2515	59	1171	249	503	15200	248	31.5	5000	3.5	30.00	159	22
Minimum	0.005	0.55	26	18	1	50	3	3	10	3	0.6	11	0.25*	0.45*	0.5*	0.6
Median	0.136	6.65	125	93	23	355	28	22	97	26	2.0	54	1.9	1.00	4	1
Mean	0.216	8.34	150	110	22	376	34	30	240	40	2.4	112	1.8	1.52	7	1

* minimum value reported as half detection limit

Appendix C: Graduated symbol geochemical maps for Scunthorpe surface and profile soils

Aluminium (surface soils only)
Antimony
Arsenic
Barium
Cadmium
Calcium (surface soils only)
Chromium
Cobalt
Copper
Iron
Lead
Magnesium (surface soils only)
Manganese
Molybdenum
Nickel
Phosphorus (surface soils only)
Potassium (surface soils only)
Silicon (surface soils only)
Tin
Titanium (surface soils only)
Uranium
Vanadium
Zinc

Note ppm = mg/kg on all maps



Scunthorpe

Surface Soils

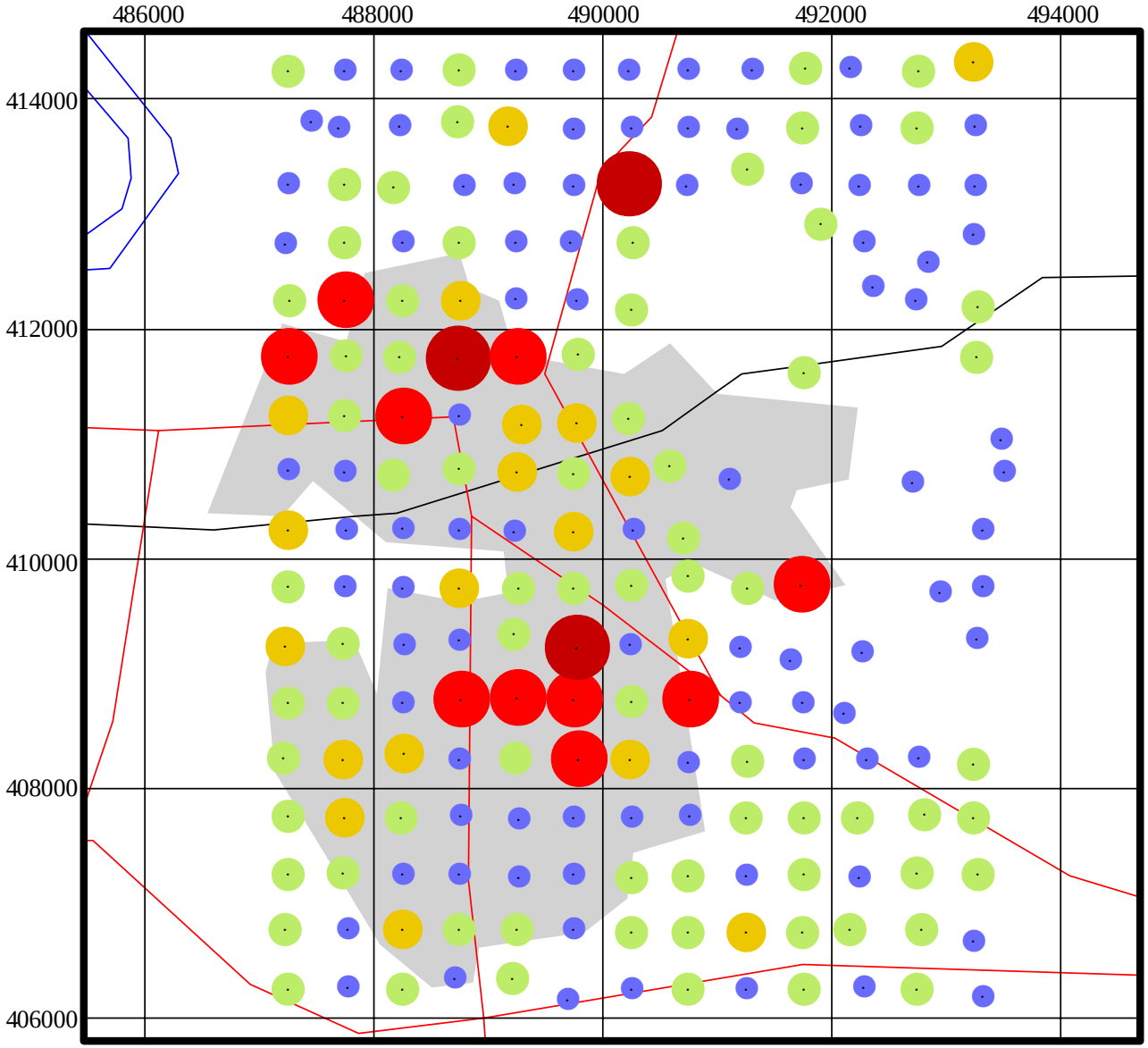
Aluminium

%ile	WT %
99	17.0
95	11.7
90	10.2
75	8.4
50	6.0
25	4.4
15	3.9
10	3.6
5	3.0

Sample locations
Major roads
Railways
Drainage
Urban area

surface soil	Al_2O_3 (%)
number	196
minimum	2.2
maximum	20.2
median	6.0
mean	6.7

Aluminium was not determined in the profile soils



Scunthorpe

Surface Soils

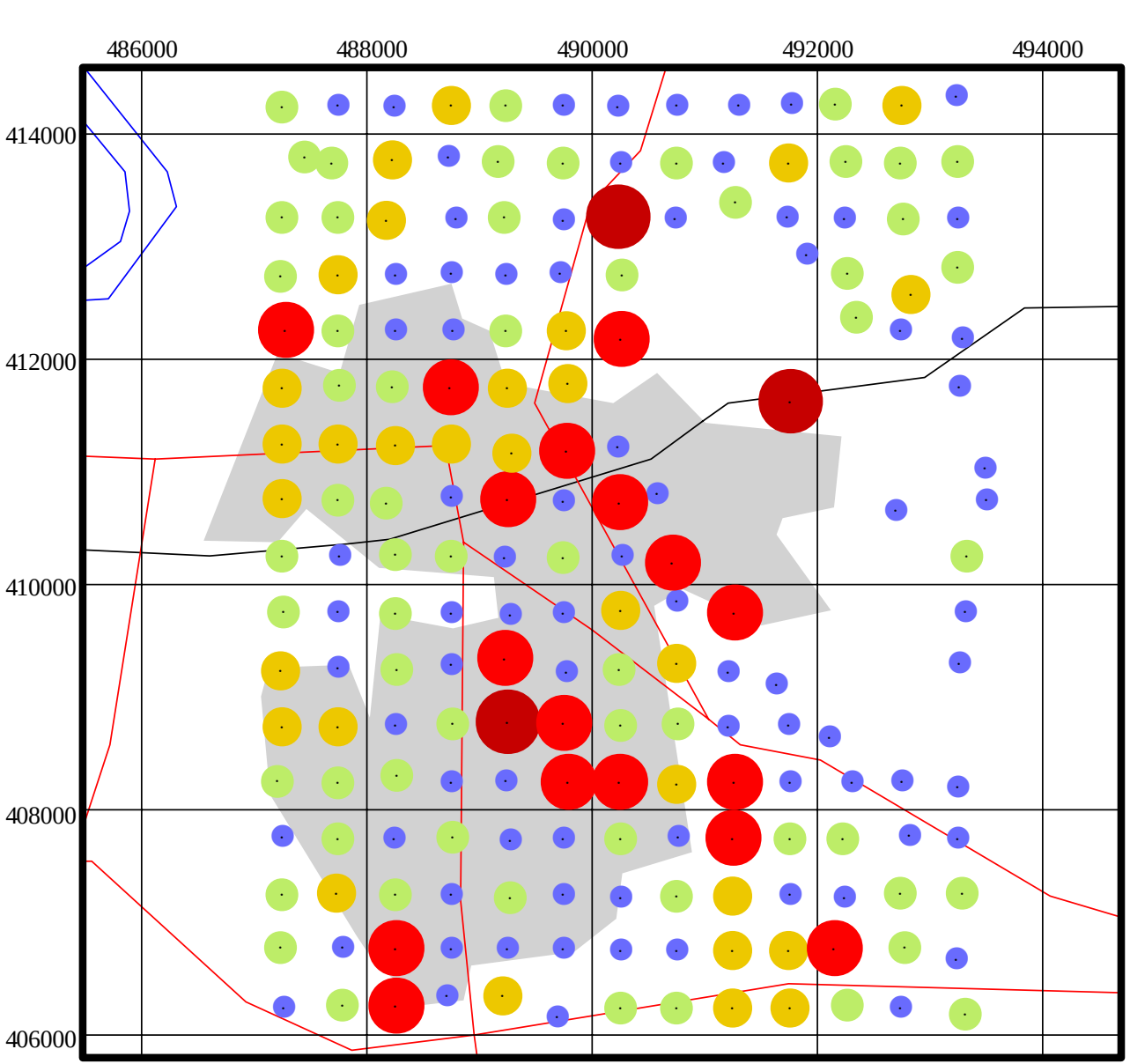
Antimony

%ile	ppm
99	6
95	3
90	2
75	1
50	0.6

Sample locations
Major roads
Railways
Drainage
Urban area

surface soil	Sb (ppm)
number	196
minimum	0.6*
maximum	19
median	1
mean	1

* minimum value reported as half detection limit



Scunthorpe

Profile Soils

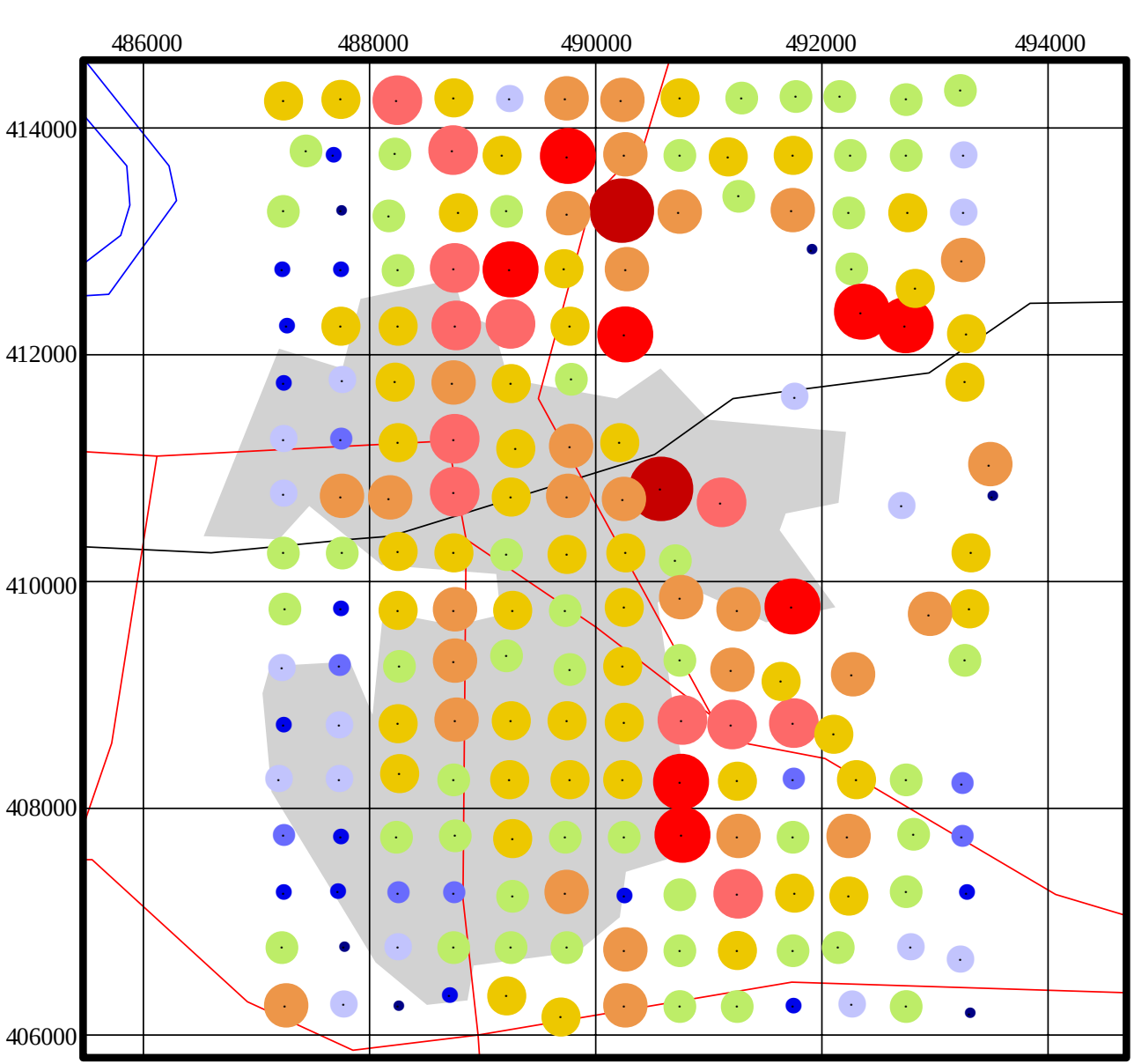
Antimony

%ile	ppm
99	8
95	3
75	2
50	1
25	0.6

Sample locations
Major roads
Railways
Drainage
Urban area

profile soil	Sb (ppm)
number	192
minimum	0.6*
maximum	22
median	1
mean	1

* minimum value reported as half detection limit



Scunthorpe

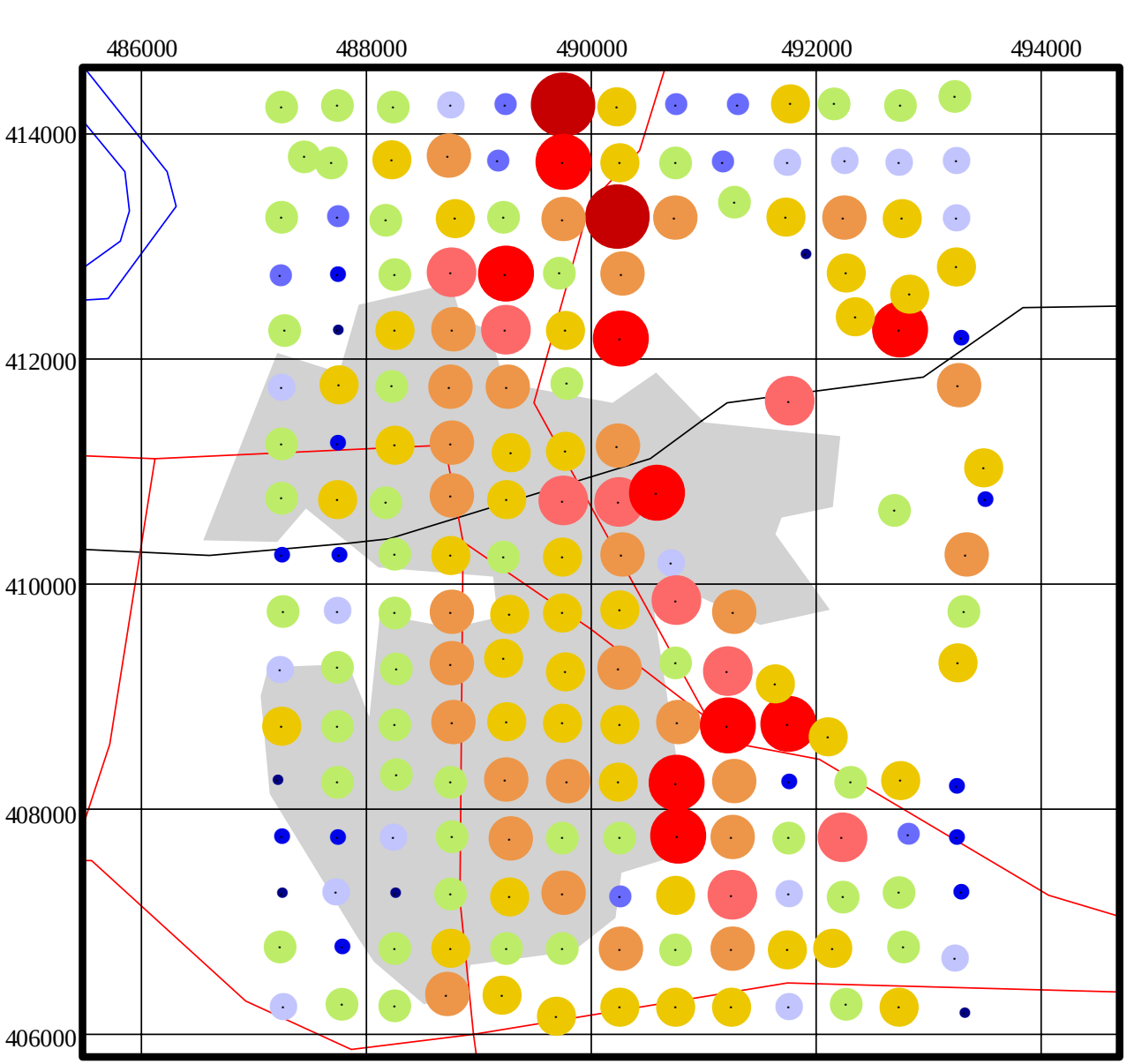
Surface Soils

Arsenic

%ile	ppm
99	146
95	73
90	46
75	31
50	19
25	11
15	9
10	8
5	6

Sample locations
Major roads
Railways
Drainage
Urban area

surface soil	As (ppm)
number	196
minimum	3
maximum	190
median	19
mean	26



Scunthorpe

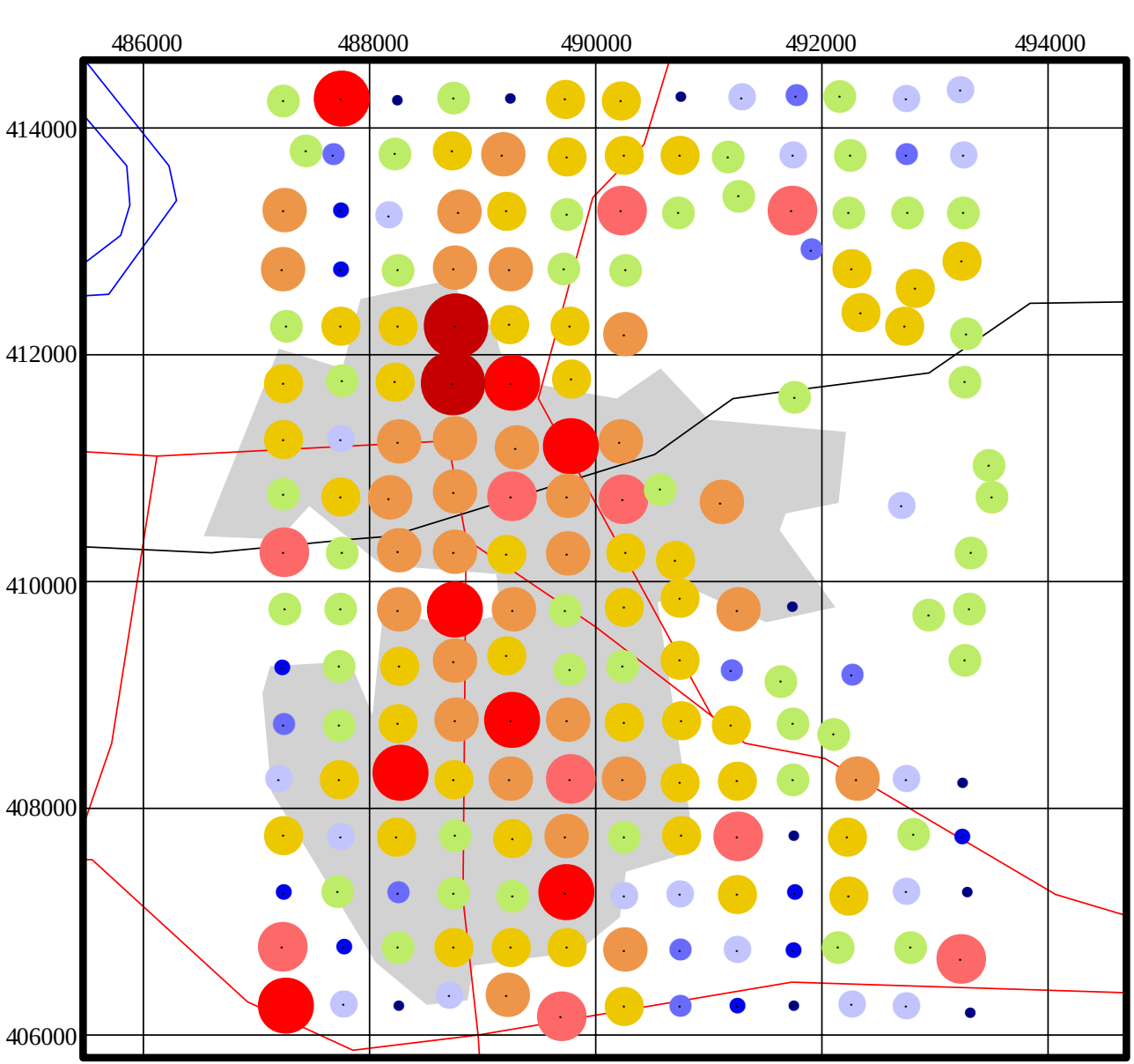
Profile Soils

Arsenic

%ile	ppm
99	233
95	119
90	78
75	49
50	26
25	17
15	14
10	11
5	6

Sample locations
Major roads
Railways
Drainage
Urban area

profile soil	As (ppm)
number	192
minimum	3
maximum	248
median	26
mean	40



Scunthorpe

Surface Soils

Barium

%ile	ppm
99	552
95	413
90	373
75	319
50	278
25	245
15	231
10	218
5	205

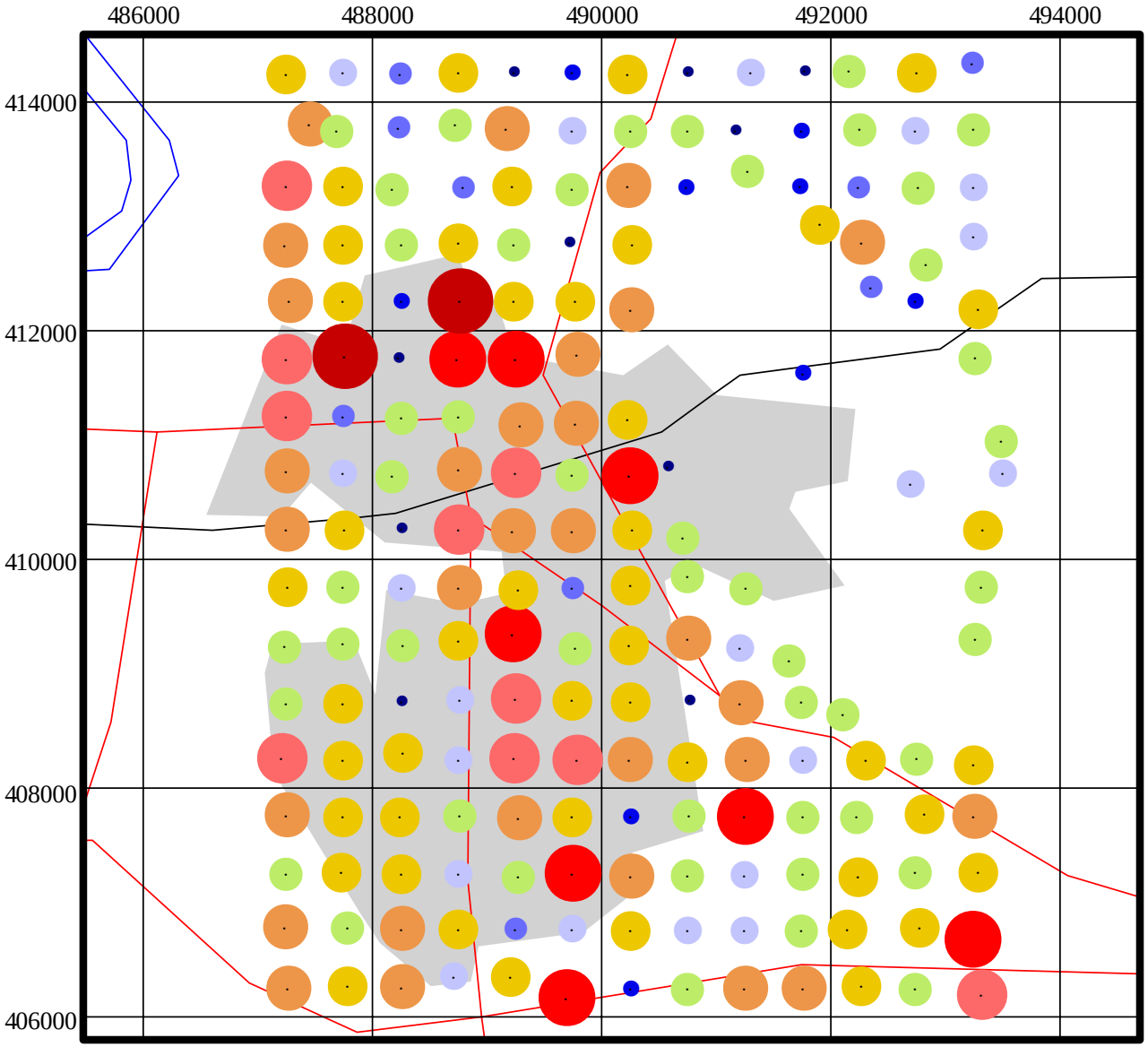
Sample locations
Major roads
Railways
Drainage
Urban area

surface soil	Ba (ppm)
number	196
minimum	165
maximum	611
median	278
mean	290

Scunthorpe

Profile Soils

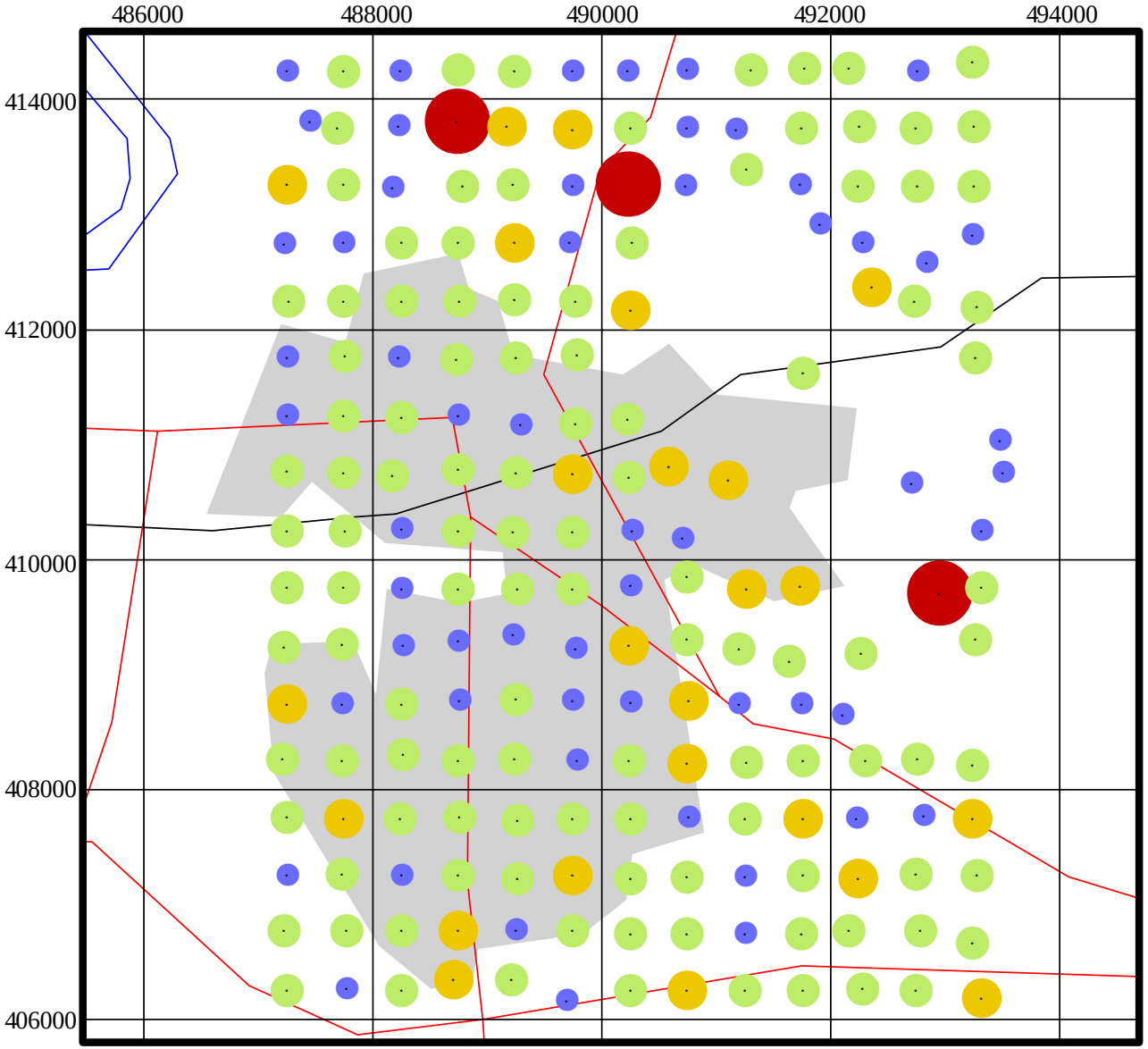
Barium



%ile	ppm
99	746
95	525
90	483
75	414
50	355
25	315
15	296
10	283
5	266

Sample locations
Major roads
Railways
Drainage
Urban area

profile soil	Ba (ppm)
number	192
minimum	50
maximum	1171
median	355
mean	376



Scunthorpe

Surface Soils

Cadmium

%ile	ppm
99	4
95	2
75	1
25	0.45

Sample locations
Major roads
Railways
Drainage
Urban area

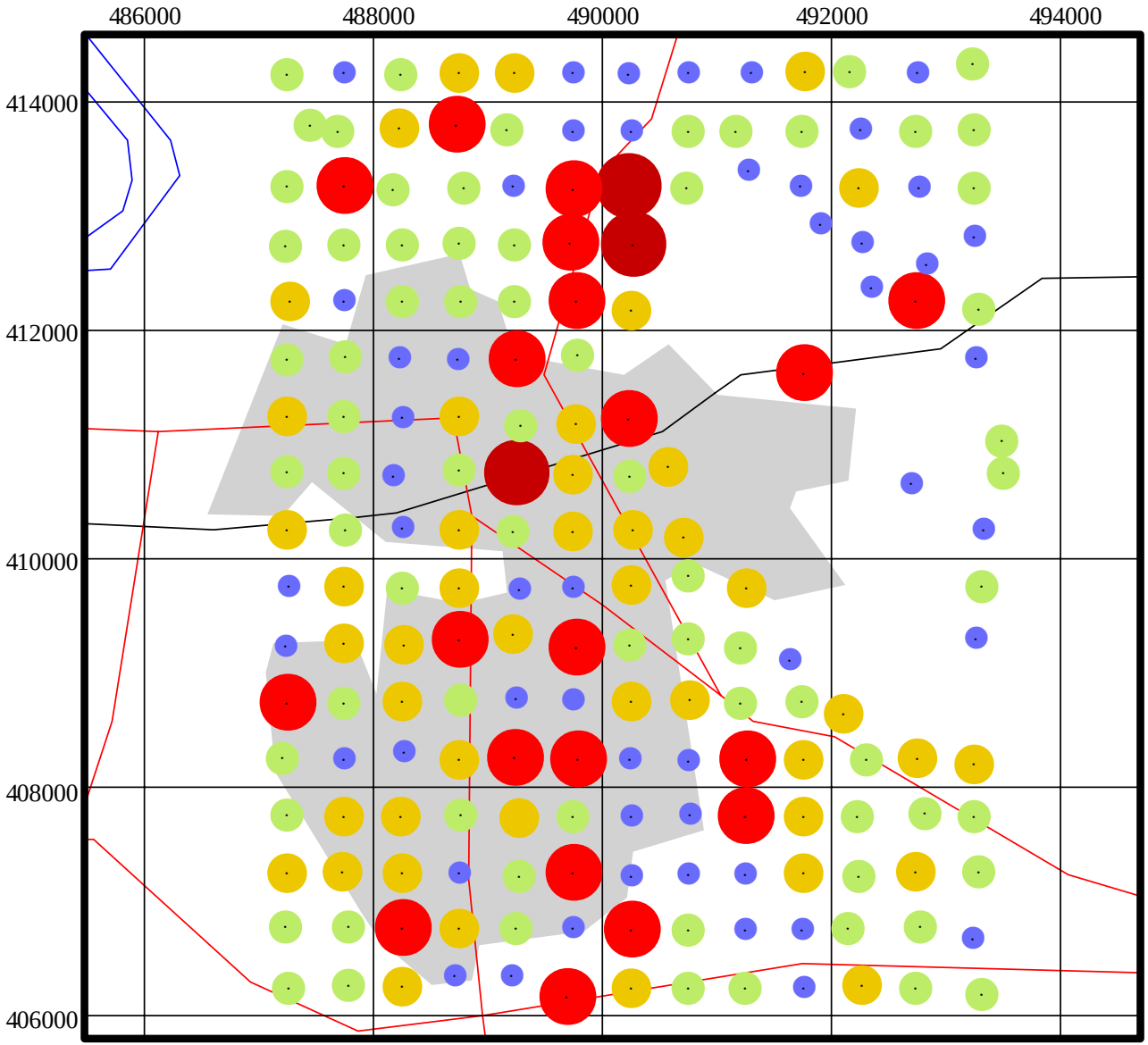
surface soil	Cd (ppm)
number	196
minimum	0.45*
maximum	28
median	1
mean	1

* minimum value reported as half detection limit

Scunthorpe

Profile Soils

Cadmium

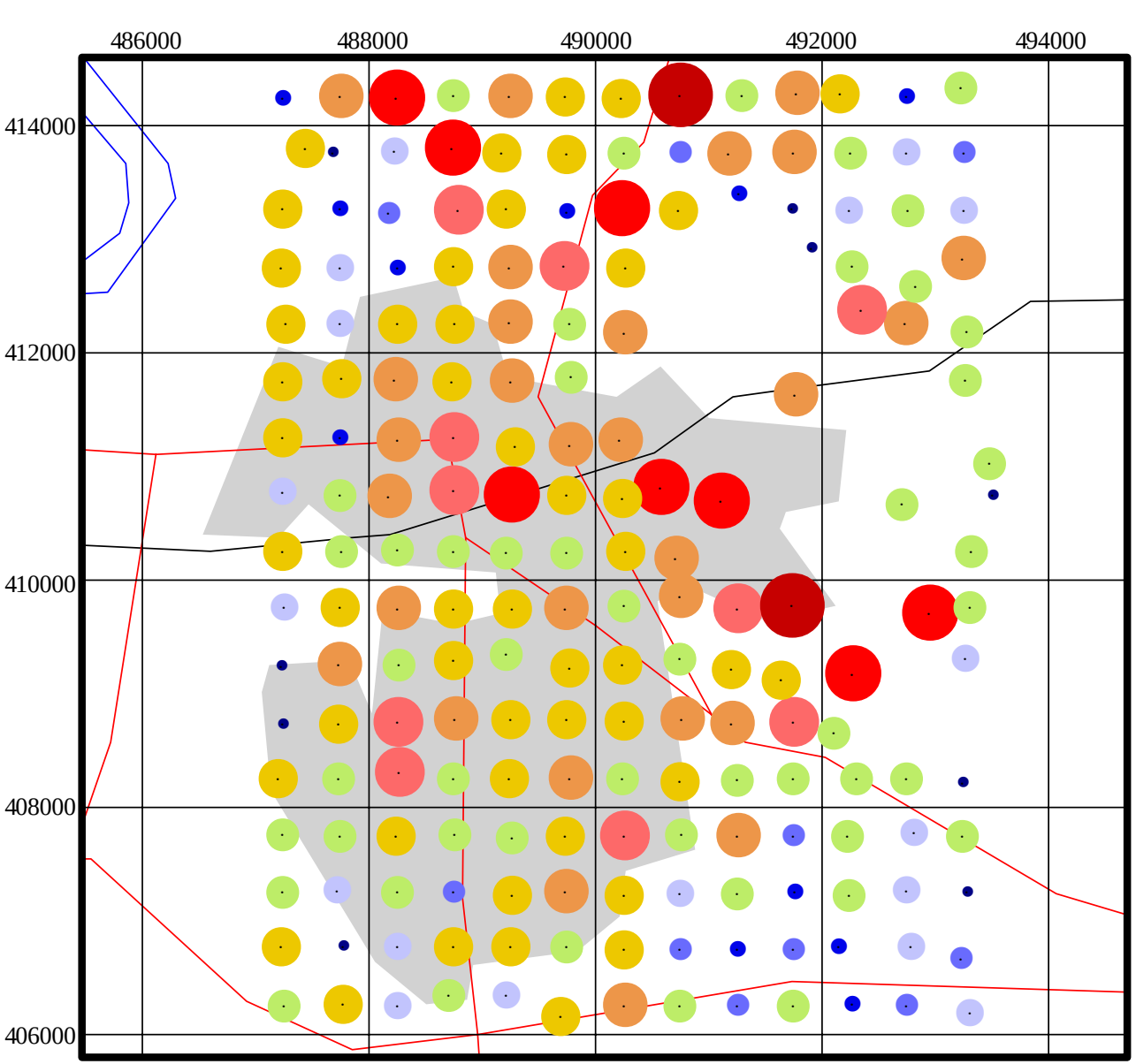


%ile	ppm
99	5
95	3
75	2
50	1
25	0.45

Sample locations
Major roads
Railways
Drainage
Urban area

profile soil	Cd (ppm)
number	192
minimum	0.45*
maximum	30
median	1
mean	2

* minimum value reported as half detection limit



Scunthorpe

Surface Soils

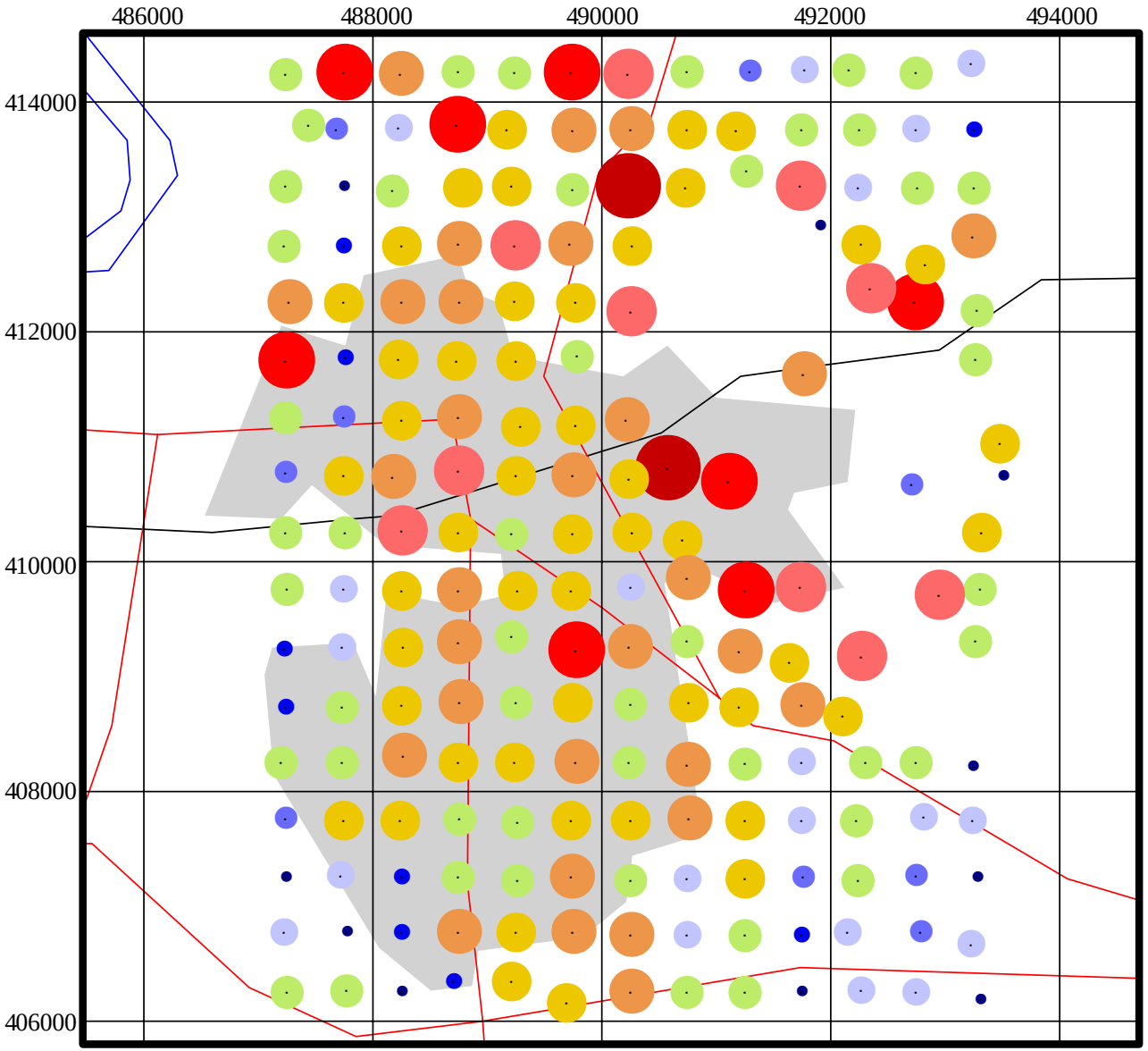
Calcium

%ile	WT %
99	11.916
95	8.219
90	5.492
75	2.340
50	0.950
25	0.449
15	0.326
10	0.244
5	0.190

Sample locations
Major roads
Railways
Drainage
Urban area

surface soil	CaO (%)
number	196
minimum	0.110
maximum	14.969
median	0.950
mean	2.041

Calcium was not determined in the profile soils



Scunthorpe

Surface Soils

Chromium

%ile	ppm
99	237
95	159
90	107
75	78
50	55
25	32
15	26
10	22
5	16

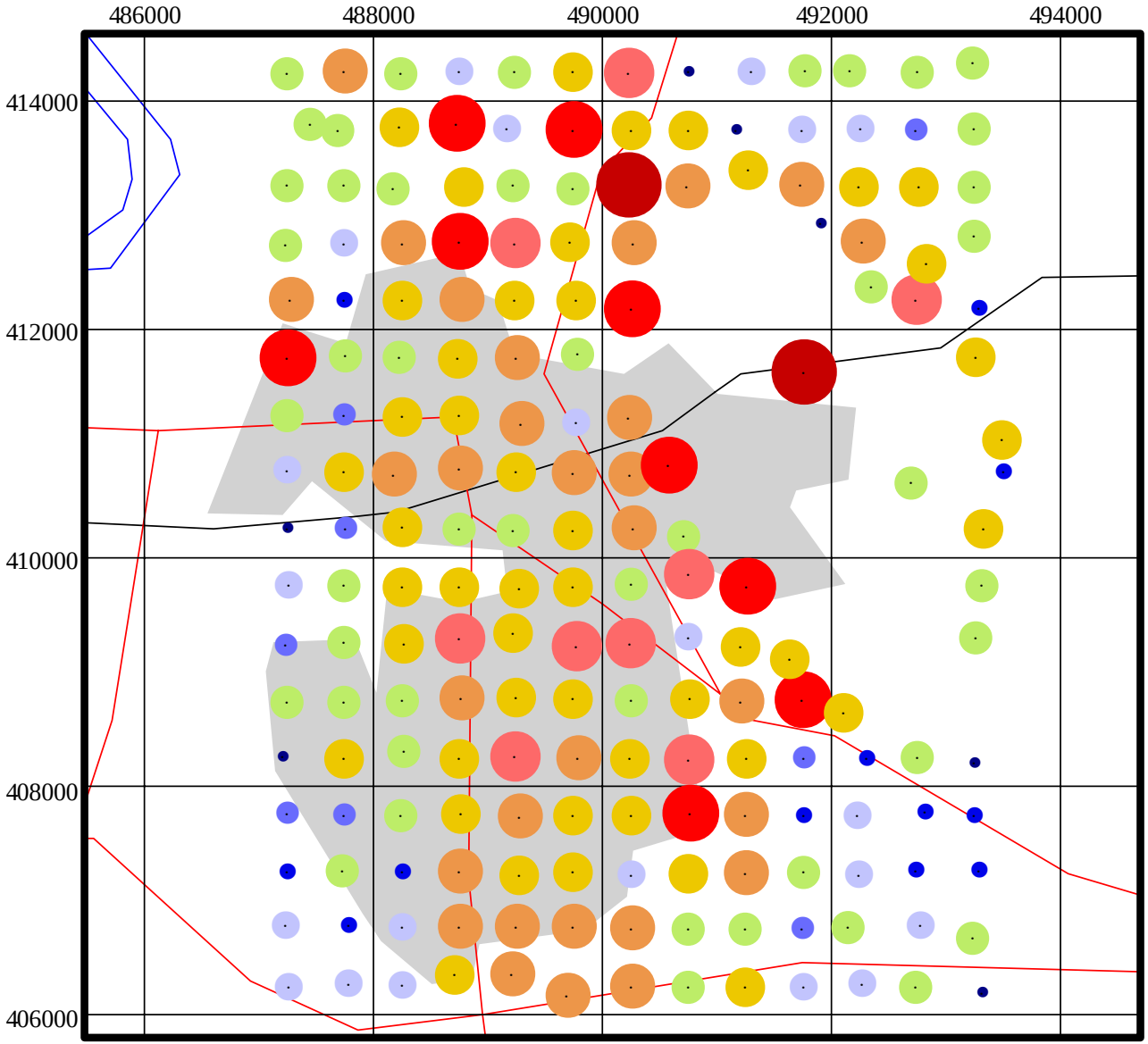
Sample locations
Major roads
Railways
Drainage
Urban area

surface soil	Cr (ppm)
number	196
minimum	7
maximum	1108
median	55
mean	67

Scunthorpe

Profile Soils

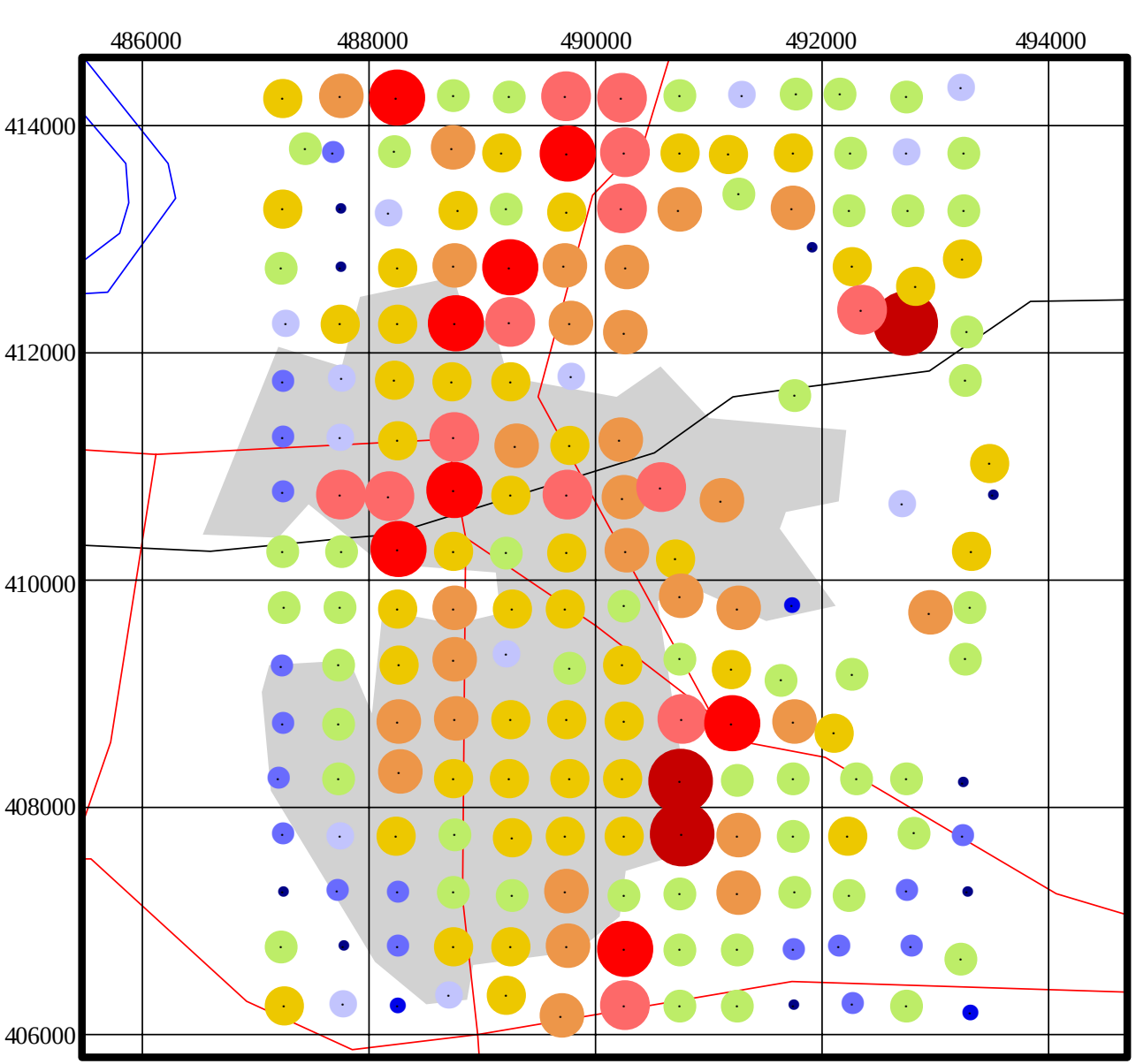
Chromium



%ile	ppm
99	508
95	162
90	142
75	116
50	93
25	64
15	50
10	41
5	34

Sample locations
Major roads
Railways
Drainage
Urban area

profile soil	Cr (ppm)
number	192
minimum	18
maximum	2515
median	93
mean	110



Scunthorpe

Surface Soils

Cobalt

%ile	ppm
99	39
95	32
90	29
75	22
50	15
25	9
15	8
10	6
5	5

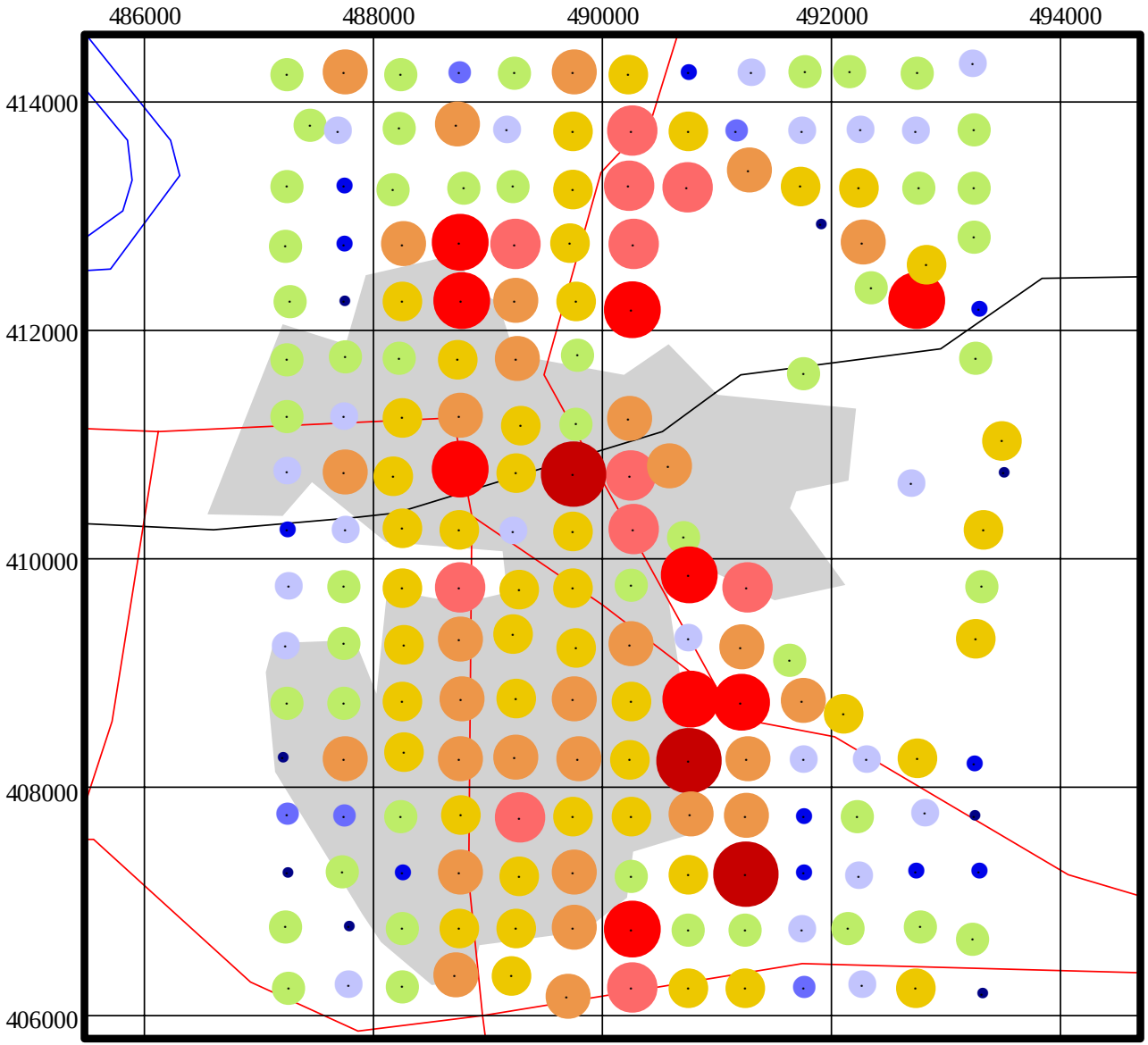
Sample locations
Major roads
Railways
Drainage
Urban area

surface soil	Co (ppm)
number	196
minimum	3
maximum	51
median	15
mean	16

Scunthorpe

Profile Soils

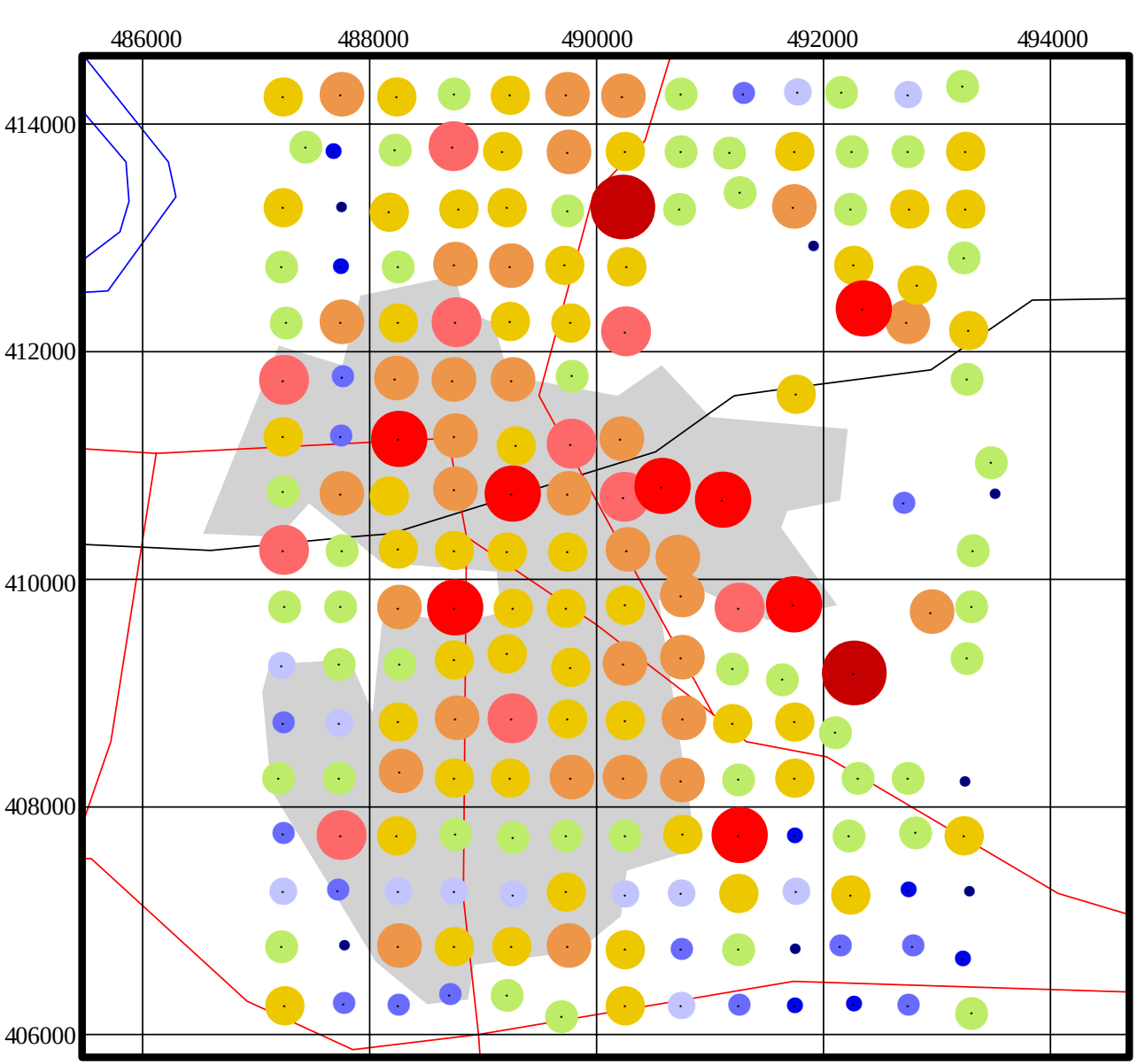
Cobalt



%ile	ppm
99	51
95	40
90	37
75	31
50	23
25	13
15	9
10	7
5	4

Sample locations
Major roads
Railways
Drainage
Urban area

profile soil	Co (ppm)
number	192
minimum	1
maximum	59
median	23
mean	22



Scunthorpe

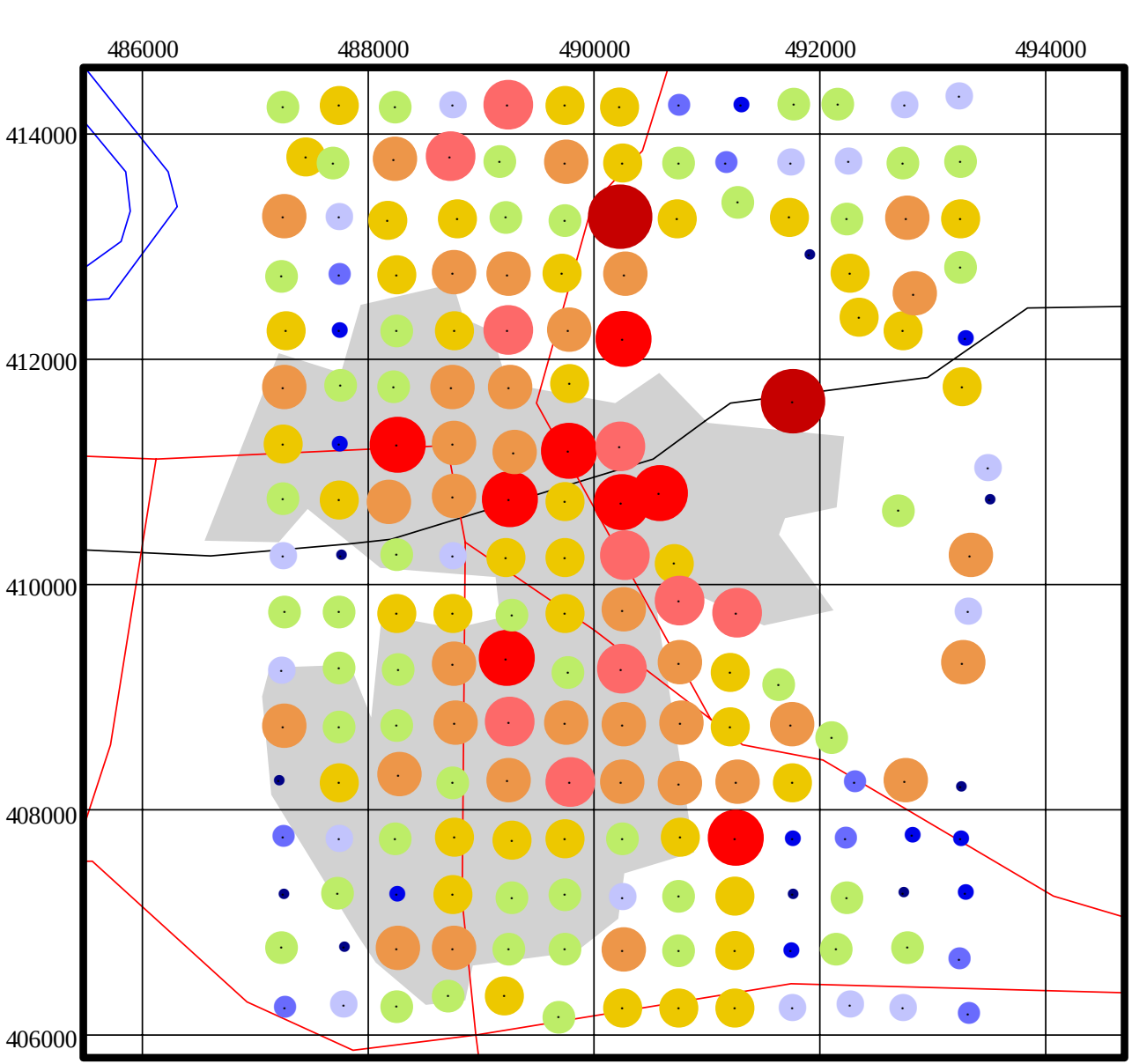
Surface Soils

Copper

%ile	ppm
99	114
95	52
90	39
75	24
50	15
25	10
15	8
10	6
5	5

Sample locations
Major roads
Railways
Drainage
Urban area

surface soil	Cu (ppm)
number	196
minimum	2
maximum	433
median	15
mean	22



Scunthorpe

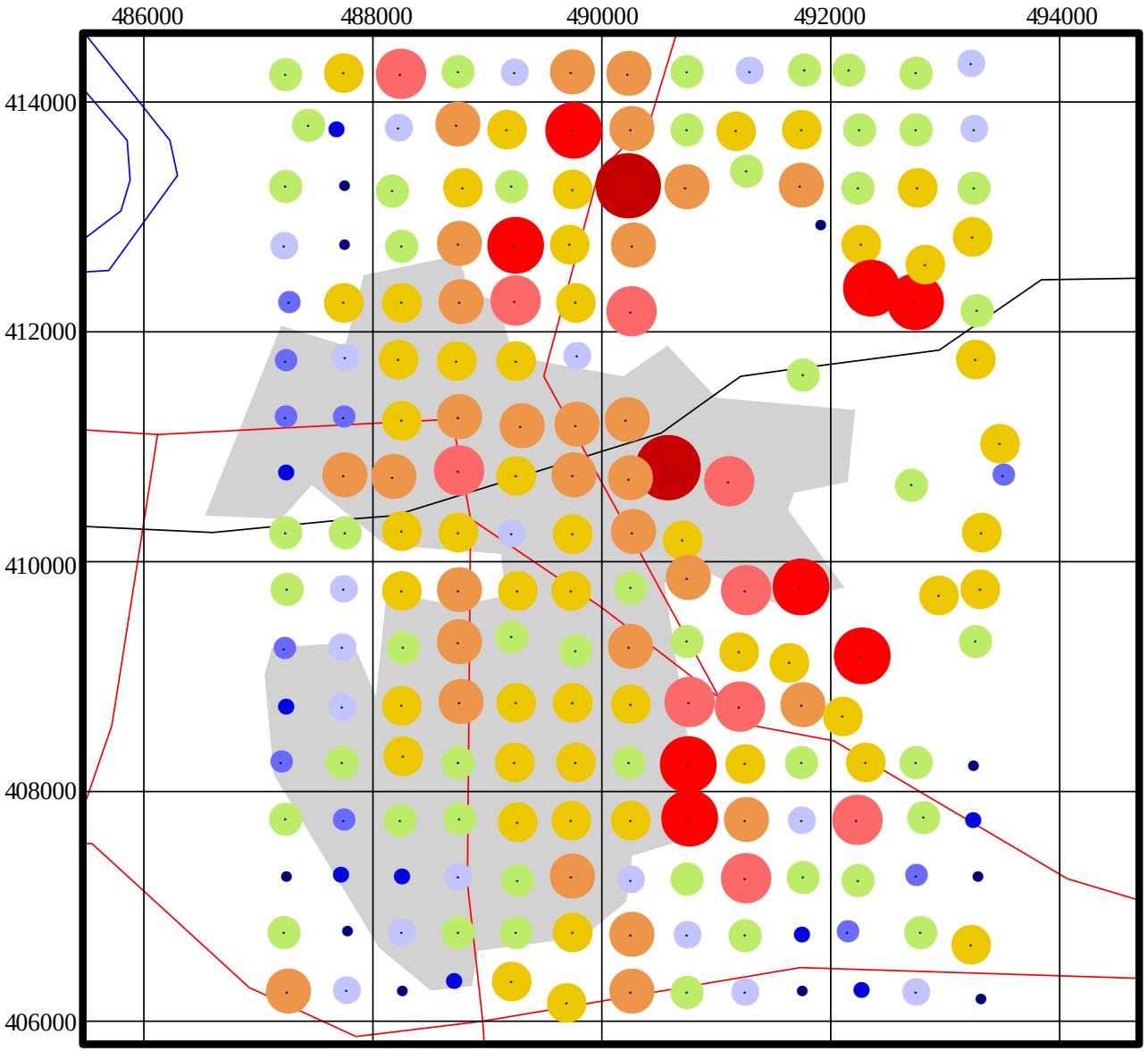
Profile Soils

Copper

%ile	ppm
99	217
95	66
90	47
75	28
50	22
25	13
15	10
10	8
5	5

Sample locations
Major roads
Railways
Drainage
Urban area

profile soil	Cu (ppm)
number	192
minimum	3
maximum	503
median	22
mean	30

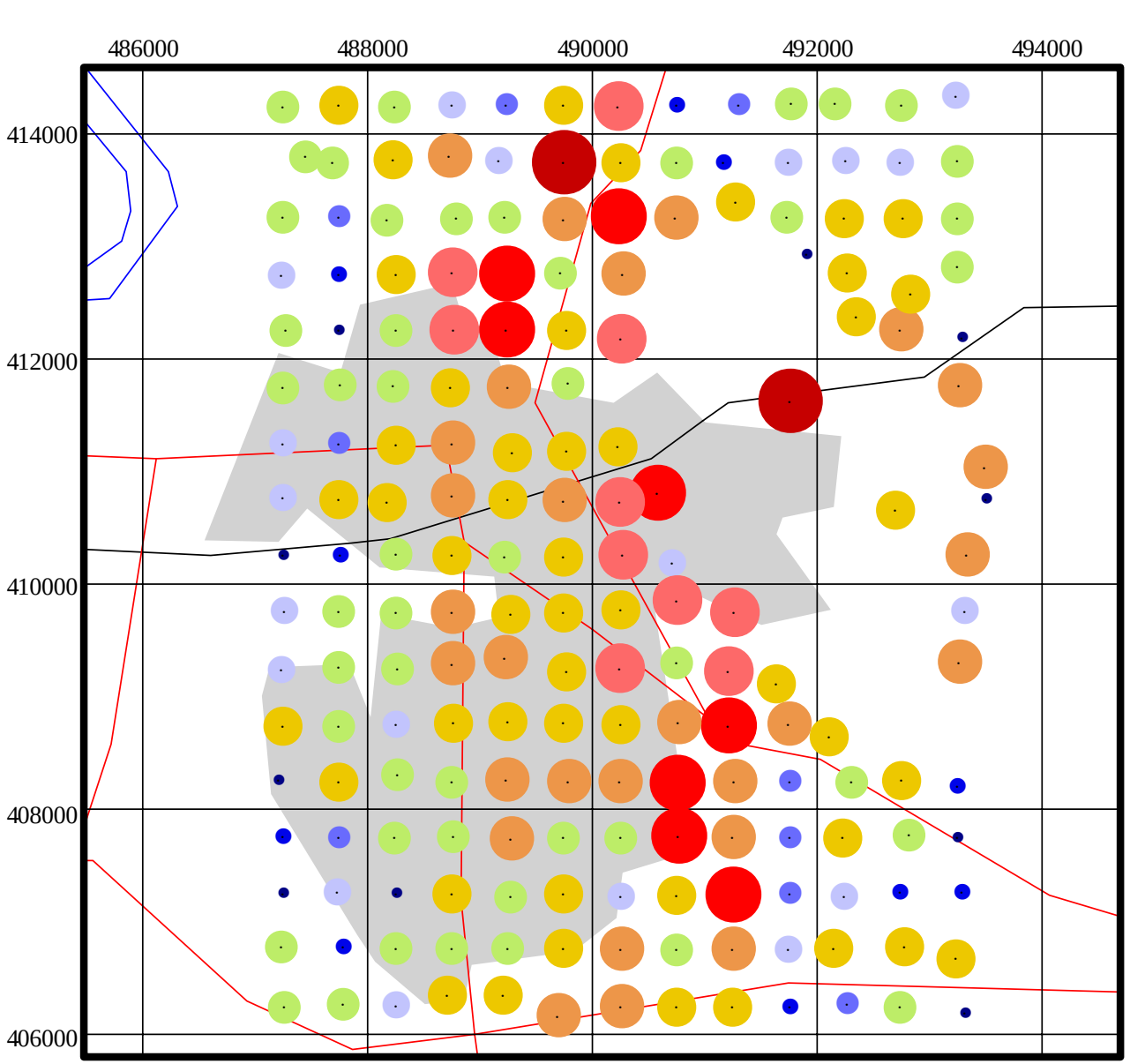


Scunthorpe
Surface Soils
Iron

%ile	WT %
99	26.83
95	15.70
90	10.60
75	7.46
50	4.63
25	2.82
15	2.27
10	1.86
5	1.23

Sample locations
Major roads
Railways
Drainage
Urban area

surface soil	Fe_2O_3 (%)
number	196
minimum	0.71
maximum	34.35
median	4.63
mean	5.97



Scunthorpe

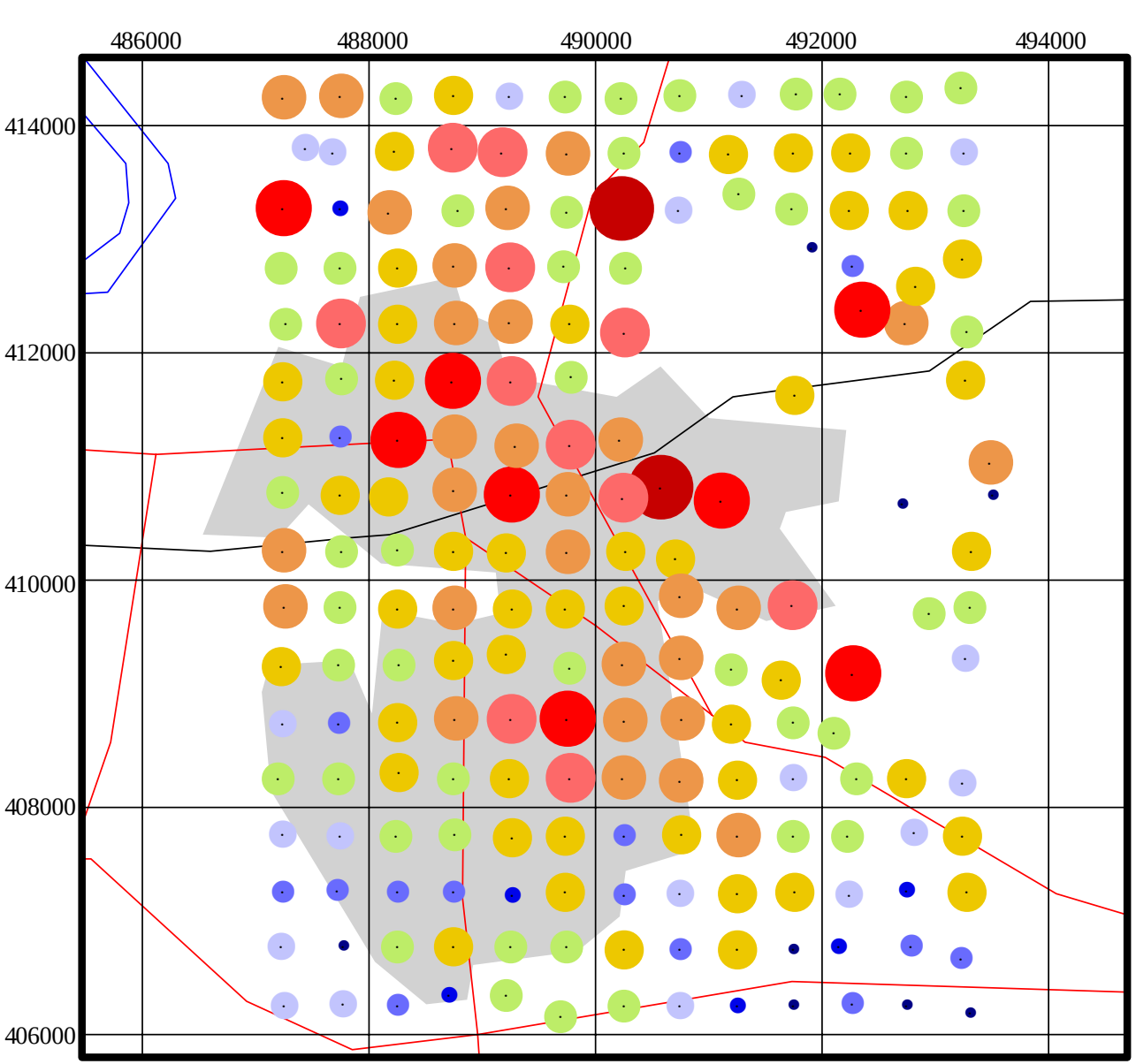
Profile Soils

Iron

%ile	WT %
99	34.00
95	20.40
90	15.85
75	10.08
50	6.65
25	4.38
15	3.17
10	2.18
5	1.22

Sample locations
Major roads
Railways
Drainage
Urban area

profile soil	Fe_2O_3 (%)
number	192
minimum	0.55
maximum	36.35
median	6.65
mean	8.34



Scunthorpe

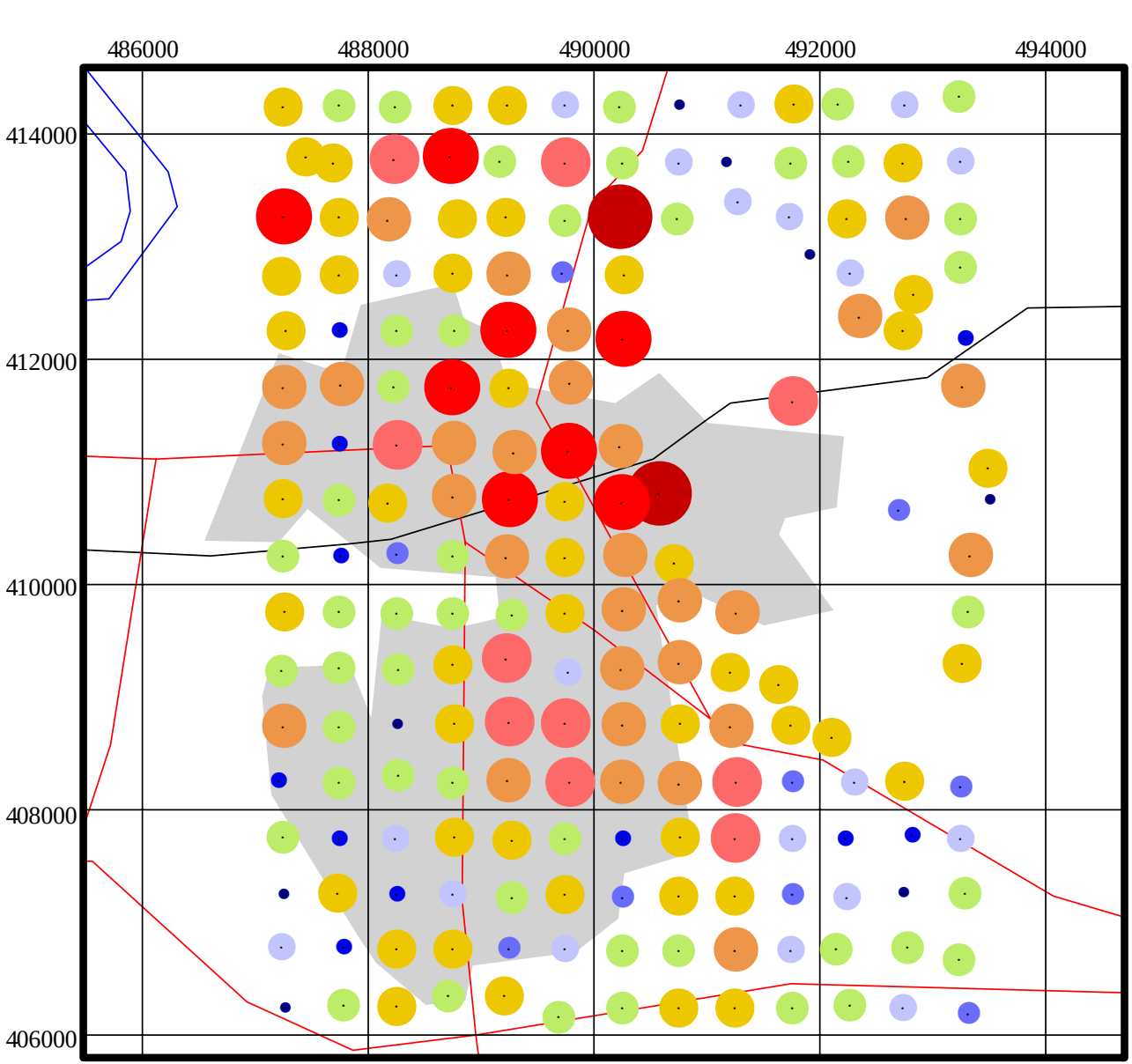
Surface Soils

Lead

%ile	ppm
99	542
95	219
90	149
75	76
50	45
25	31
15	25
10	21
5	19

Sample locations
Major roads
Railways
Drainage
Urban area

surface soil	Pb (ppm)
number	196
minimum	9
maximum	3300
median	45
mean	89



Scunthorpe

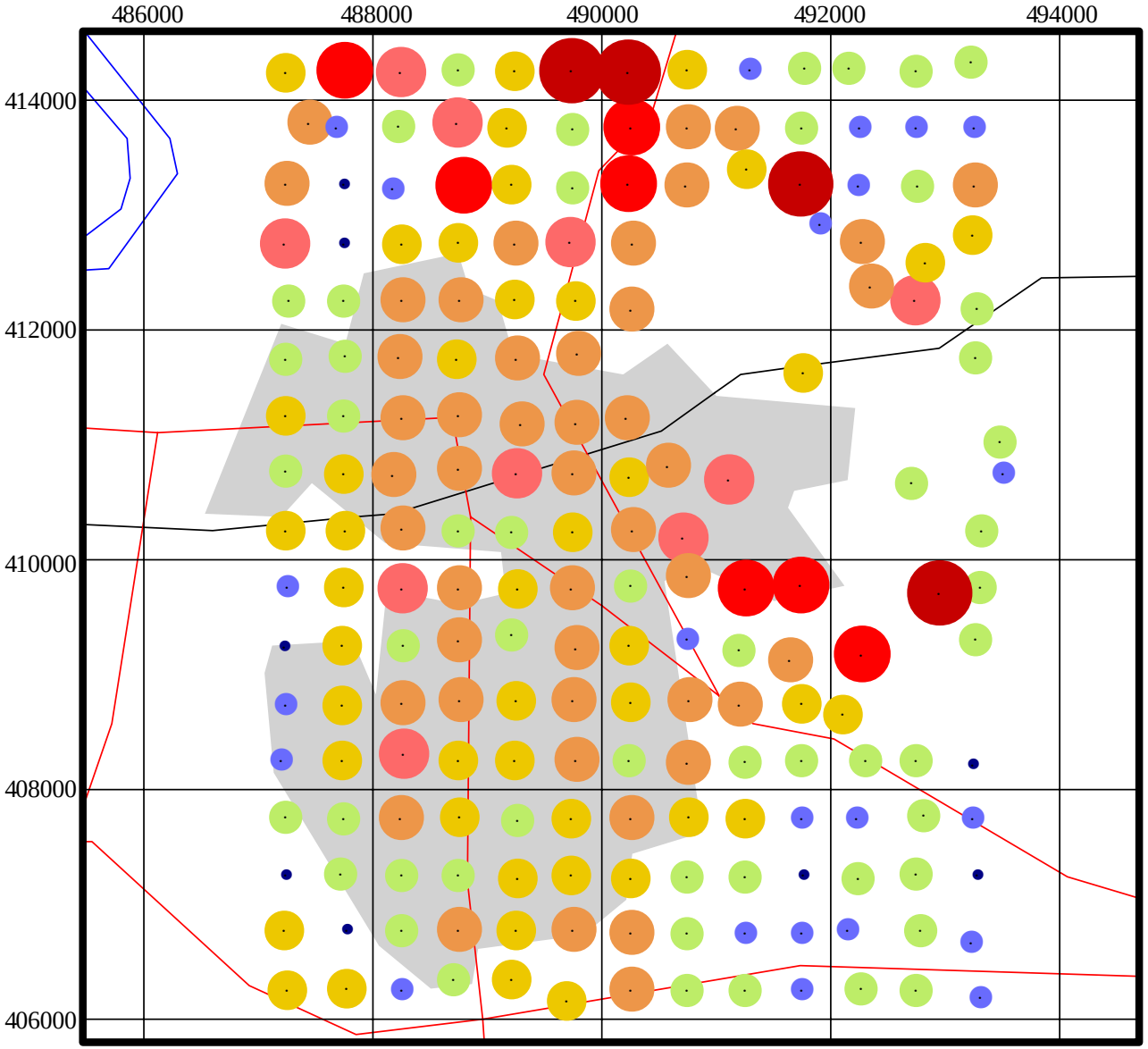
Profile Soils

Lead

%ile	ppm
99	650
95	259
90	182
75	99
50	54
25	34
15	24
10	20
5	17

Sample locations
Major roads
Railways
Drainage
Urban area

profile soil	Pb (ppm)
number	192
minimum	11
maximum	5000
median	54
mean	112



Scunthorpe

Surface Soils

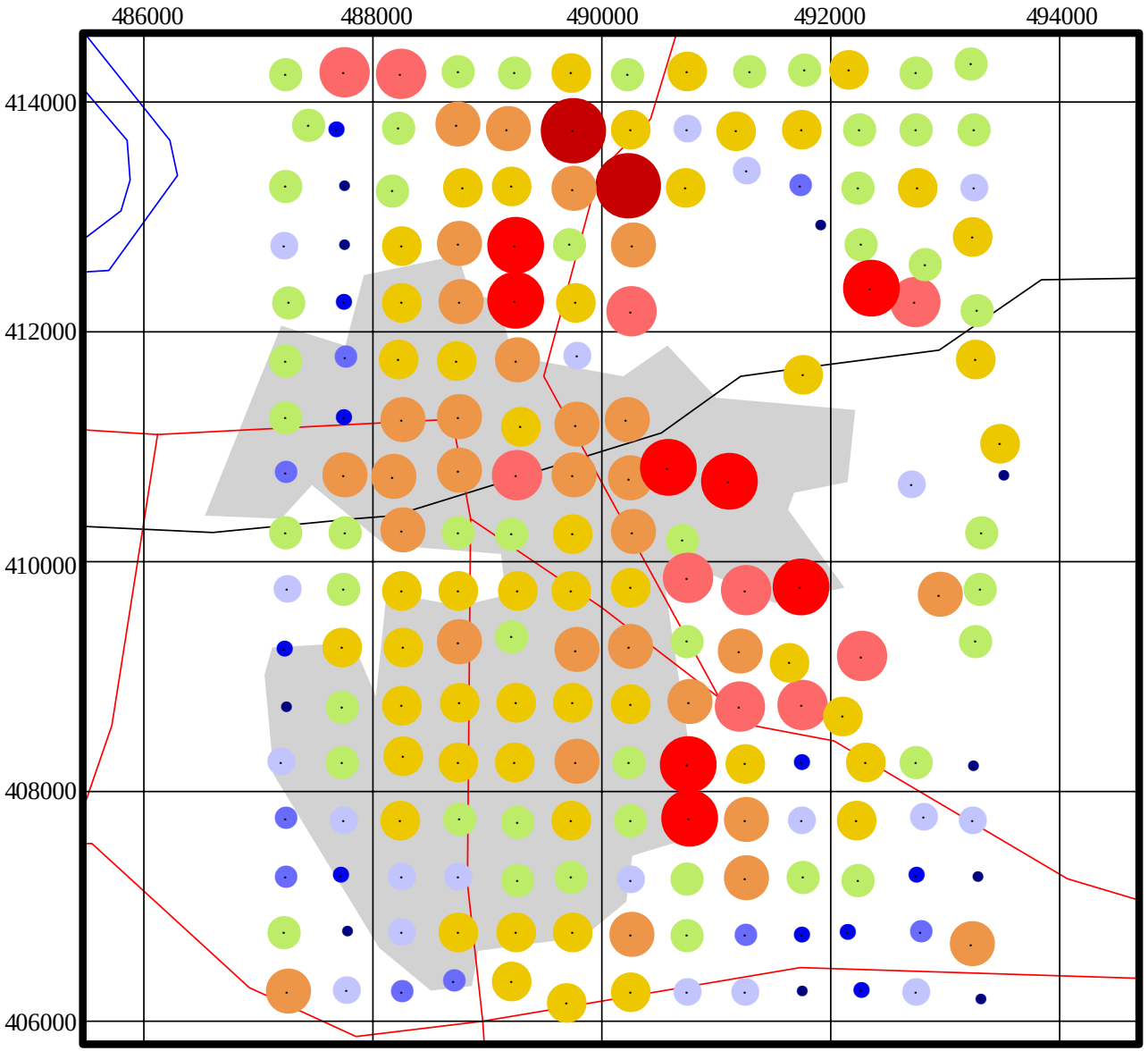
Magnesium

%ile	WT %
99	1.7
95	1.3
90	1.0
75	0.7
50	0.5
25	0.3
15	0.2

Sample locations
Major roads
Railways
Drainage
Urban area

surface soil	MgO (%)
number	196
minimum	0.1
maximum	1.9
median	0.5
mean	0.6

Magnesium was not determined in the profile soils



Scunthorpe

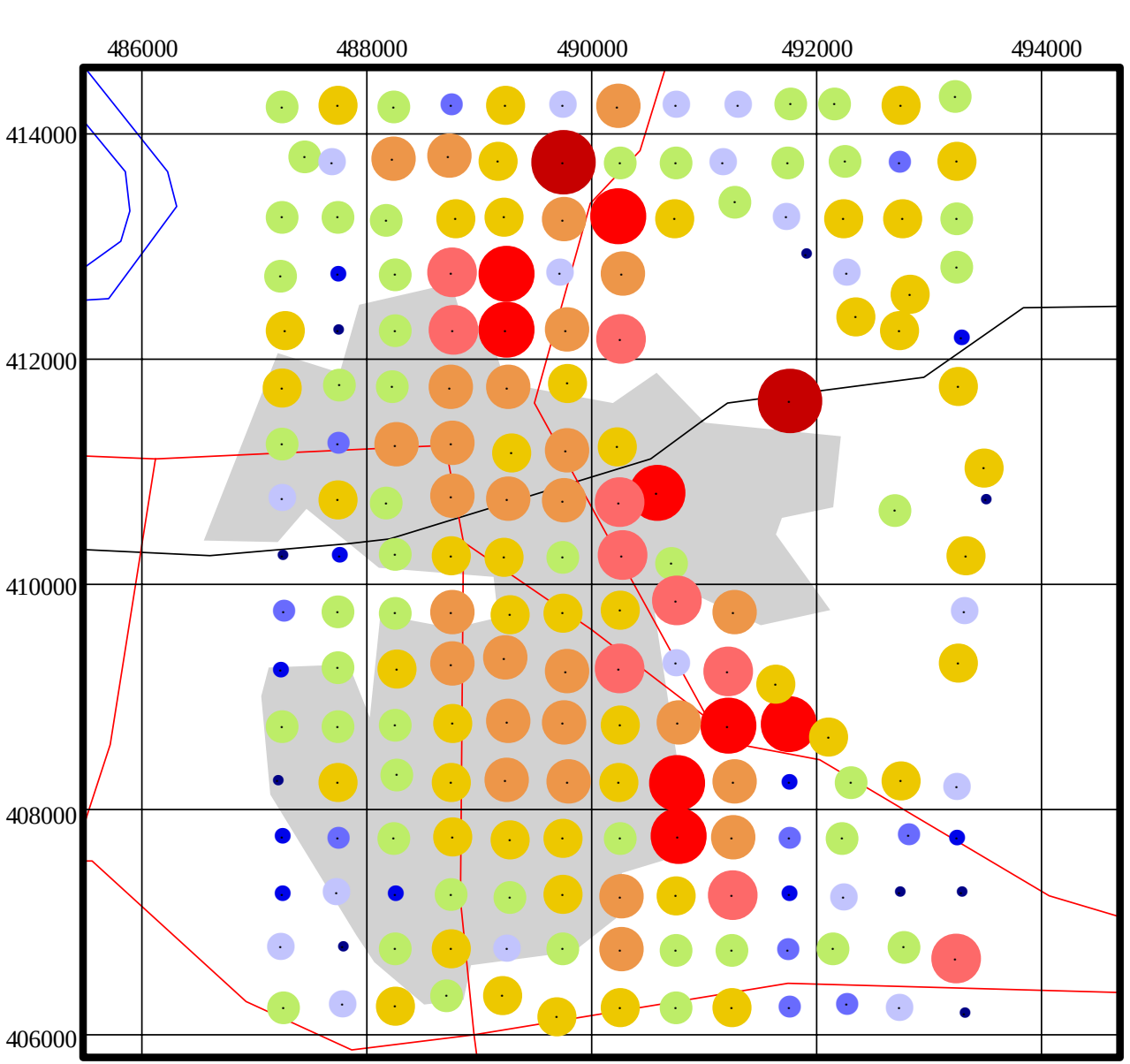
Surface Soils

Manganese

%ile	WT %
99	0.796
95	0.401
90	0.268
75	0.179
50	0.103
25	0.070
15	0.057
10	0.052
5	0.038

Sample locations
Major roads
Railways
Drainage
Urban area

surface soil	MnO (%)
number	196
minimum	0.032
maximum	1.288
median	0.103
mean	0.151



Scunthorpe

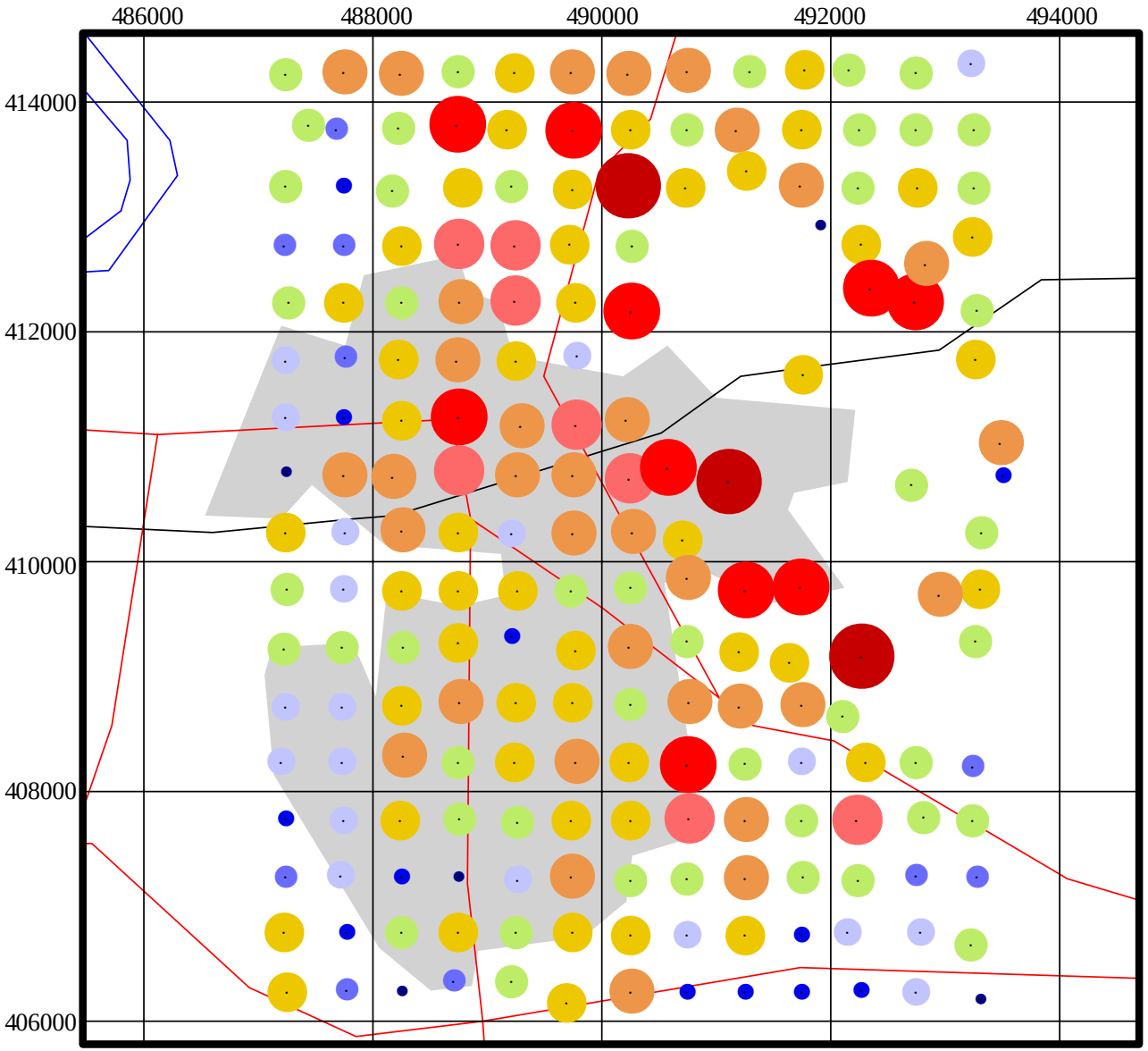
Profile Soils

Manganese

%ile	WT %
99	1.193
95	0.675
90	0.462
75	0.241
50	0.136
25	0.072
15	0.039
10	0.028
5	0.018

Sample locations
Major roads
Railways
Drainage
Urban area

profile soil	Mn O (%)
number	192
minimum	0.005
maximum	2.040
median	0.136
mean	0.216



Scunthorpe

Surface Soils

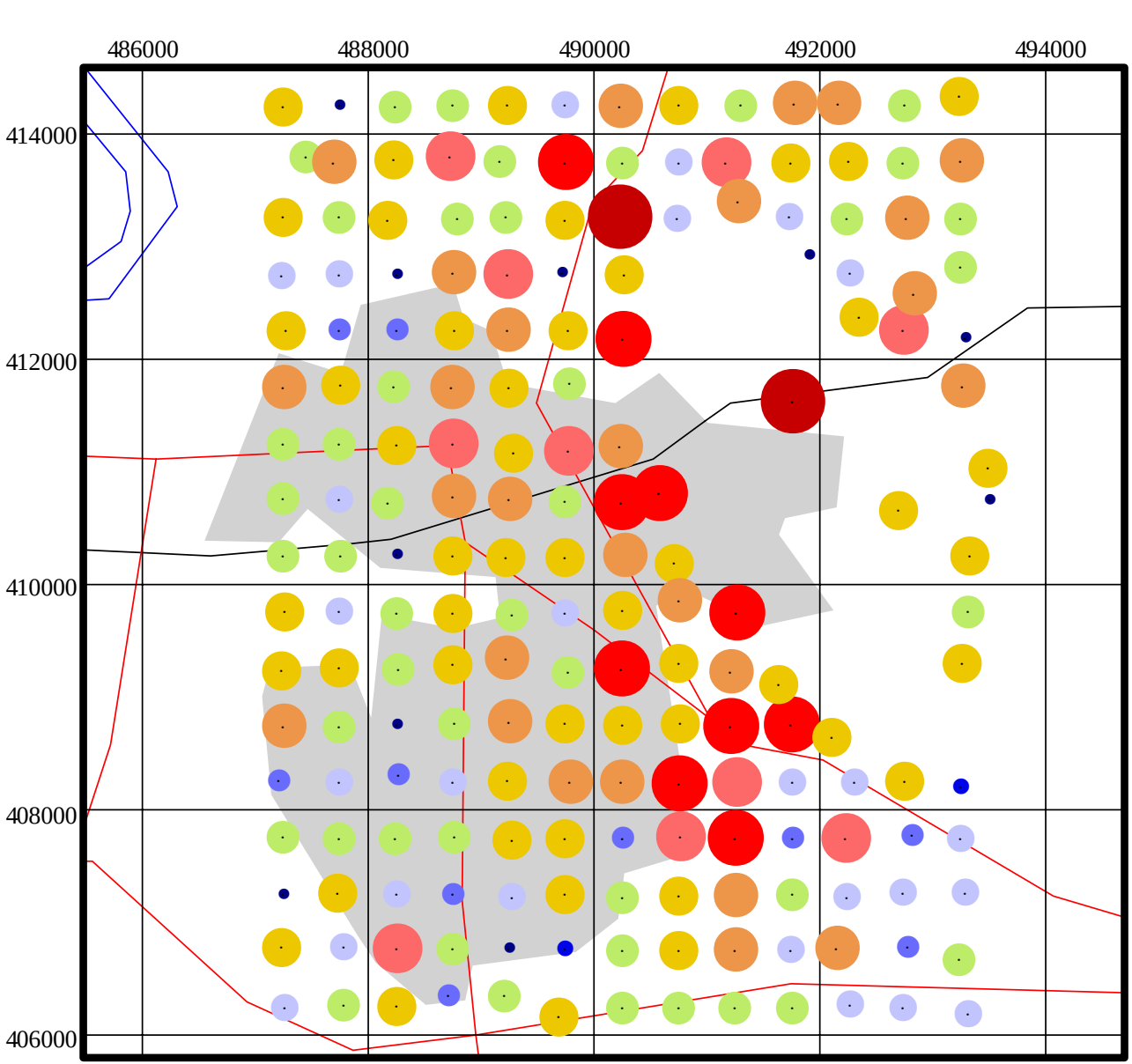
Molybdenum

%ile	ppm
99	6.4
95	3.6
90	3.2
75	2.4
50	1.6
25	0.9
15	0.7
10	0.6
5	0.4

Sample locations
Major roads
Railways
Drainage
Urban area

surface soil	Mo (ppm)
number	196
minimum	0.25*
maximum	26.1
median	1.6
mean	1.9

* minimum value reported as half detection limit



Scunthorpe

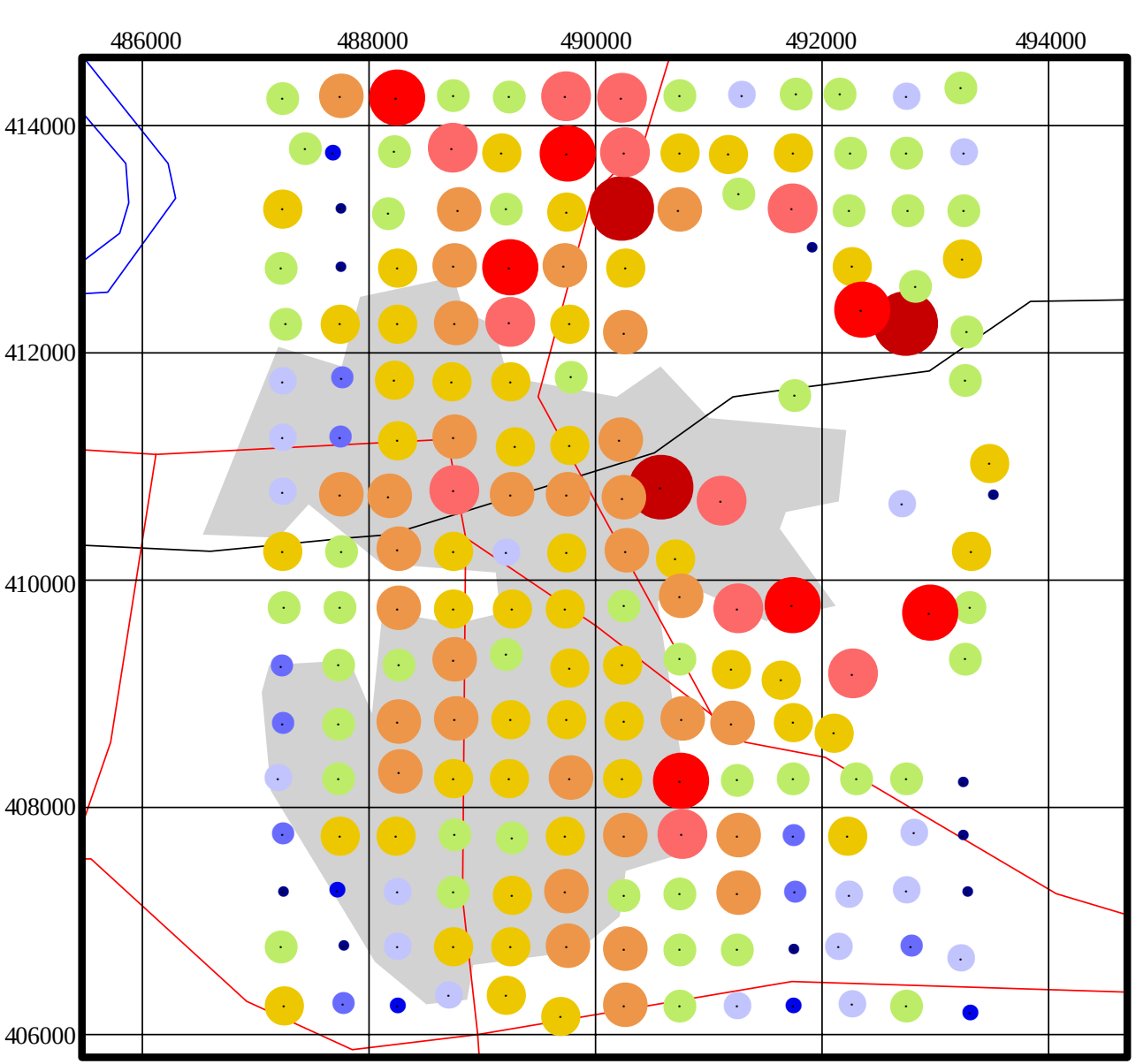
Profile Soils

Molybdenum

%ile	ppm
99	9.1
95	4.3
90	3.7
75	2.6
50	2.0
25	1.5
15	1.2
10	1.1
5	1.0

Sample locations
Major roads
Railways
Drainage
Urban area

profile soil	Mo (ppm)
number	192
minimum	0.6
maximum	31.5
median	2.0
mean	2.4

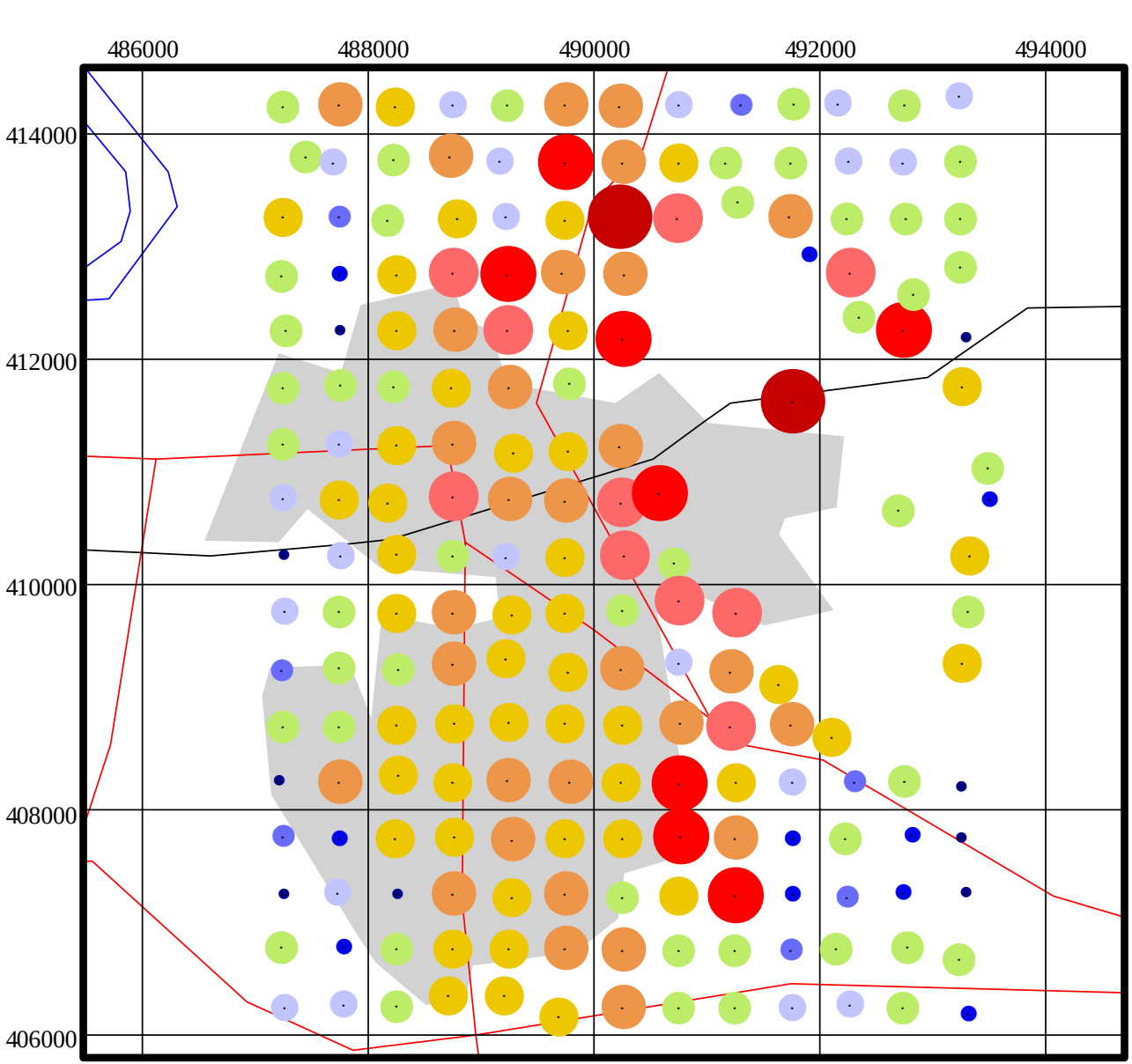


Scunthorpe
Surface Soils
Nickel

%ile	ppm
99	104
95	52
90	41
75	27
50	15
25	8
15	6
10	5
5	4

Sample locations
Major roads
Railways
Drainage
Urban area

surface soil	Ni (ppm)
number	196
minimum	1
maximum	202
median	15
mean	21



Scunthorpe

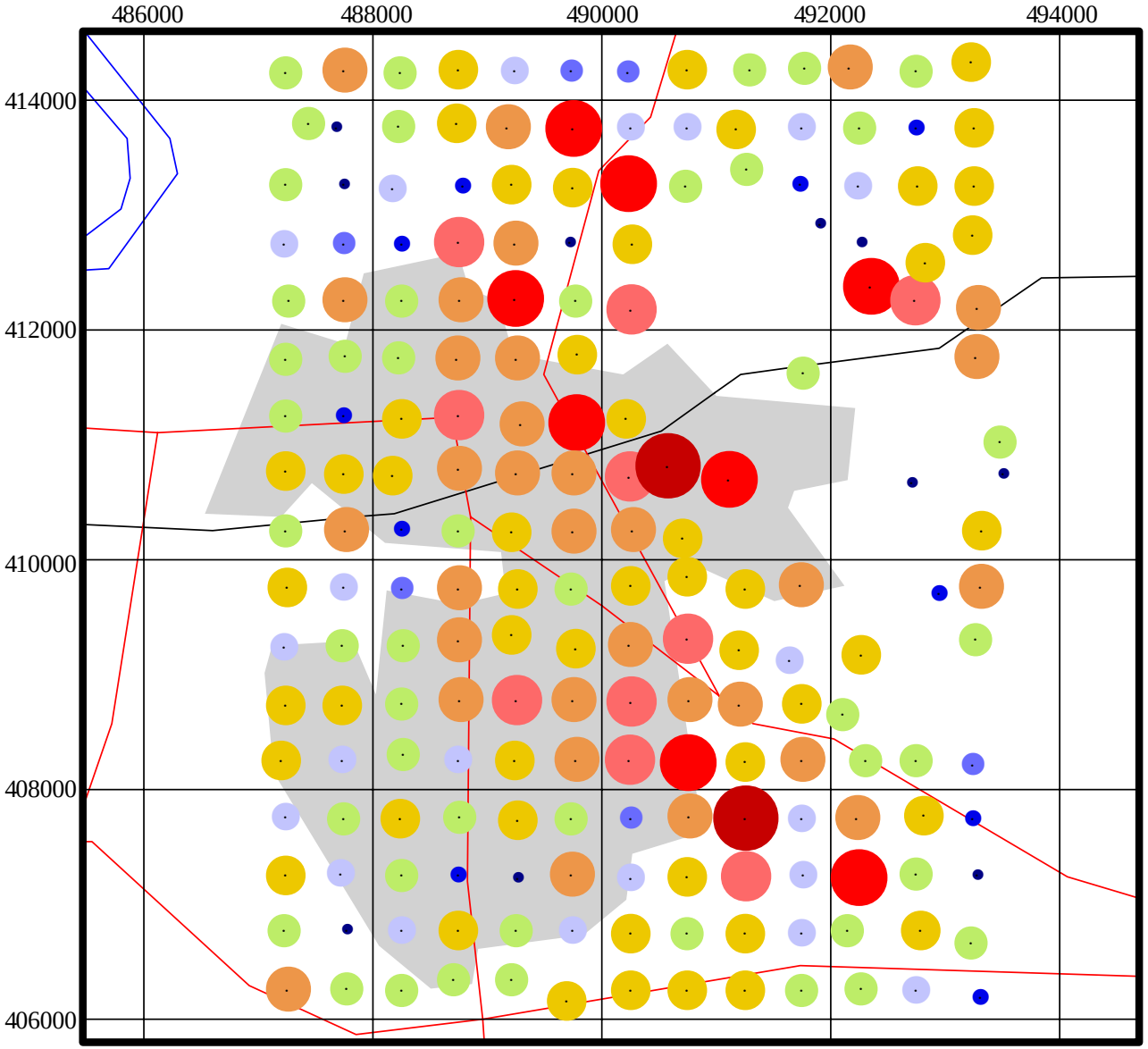
Profile Soils

Nickel

%ile	ppm
99	129
95	74
90	62
75	45
50	28
25	15
15	11
10	9
5	5

Sample locations
Major roads
Railways
Drainage
Urban area

profile soil	Ni (ppm)
number	192
minimum	3
maximum	249
median	28
mean	34



Scunthorpe

Surface Soils

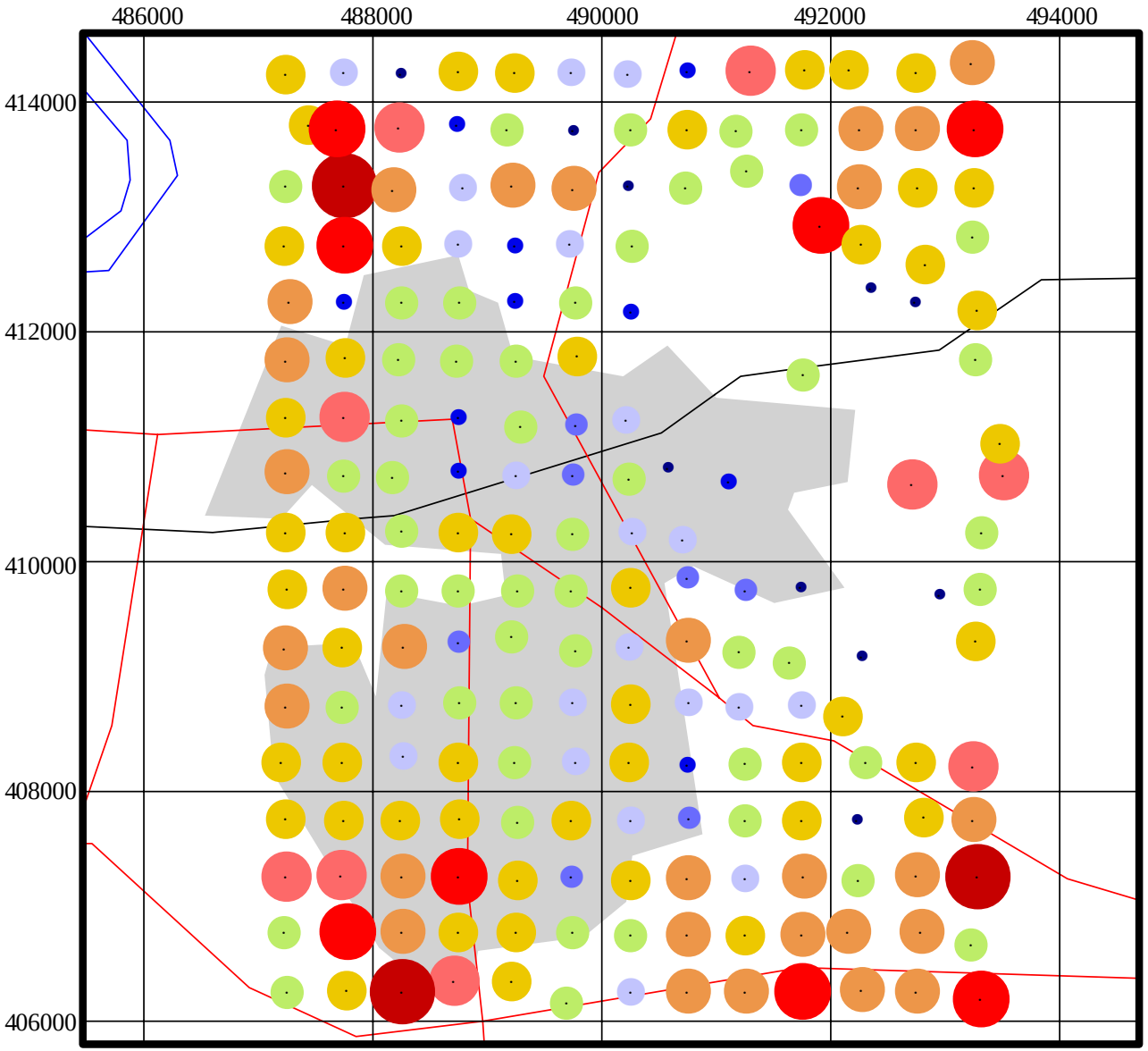
Phosphorus

%ile	WT %
99	0.897
95	0.643
90	0.535
75	0.400
50	0.260
25	0.190
15	0.170
10	0.155
5	0.138

Sample locations
Major roads
Railways
Drainage
Urban area

surface soil	P_2O_5 (%)
number	196
minimum	0.025
maximum	1.210
median	0.260
mean	0.313

Phosphorus was not determined in the profile soils



Scunthorpe

Surface Soils

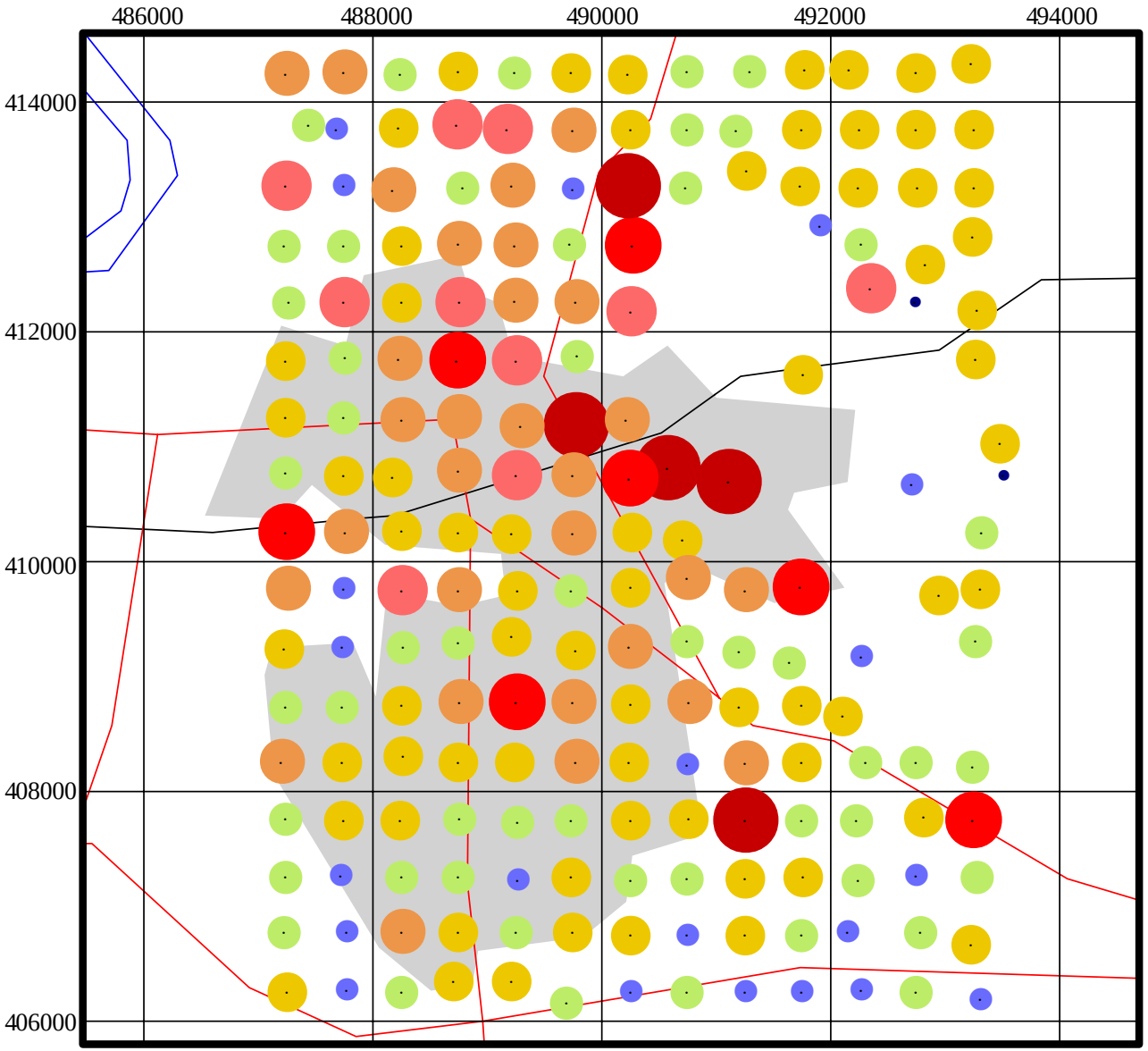
Silicon

%ile	WT %
99	80.1
95	75.7
90	73.3
75	68.2
50	63.1
25	55.2
15	51.1
10	48.3
5	43.0

Sample locations
Major roads
Railways
Drainage
Urban area

surface soil	SiO_2 (%)
number	196
minimum	17.2
maximum	81.0
median	63.1
mean	61.1

Silicon was not determined in the profile soils



Scunthorpe

Surface Soils

Tin

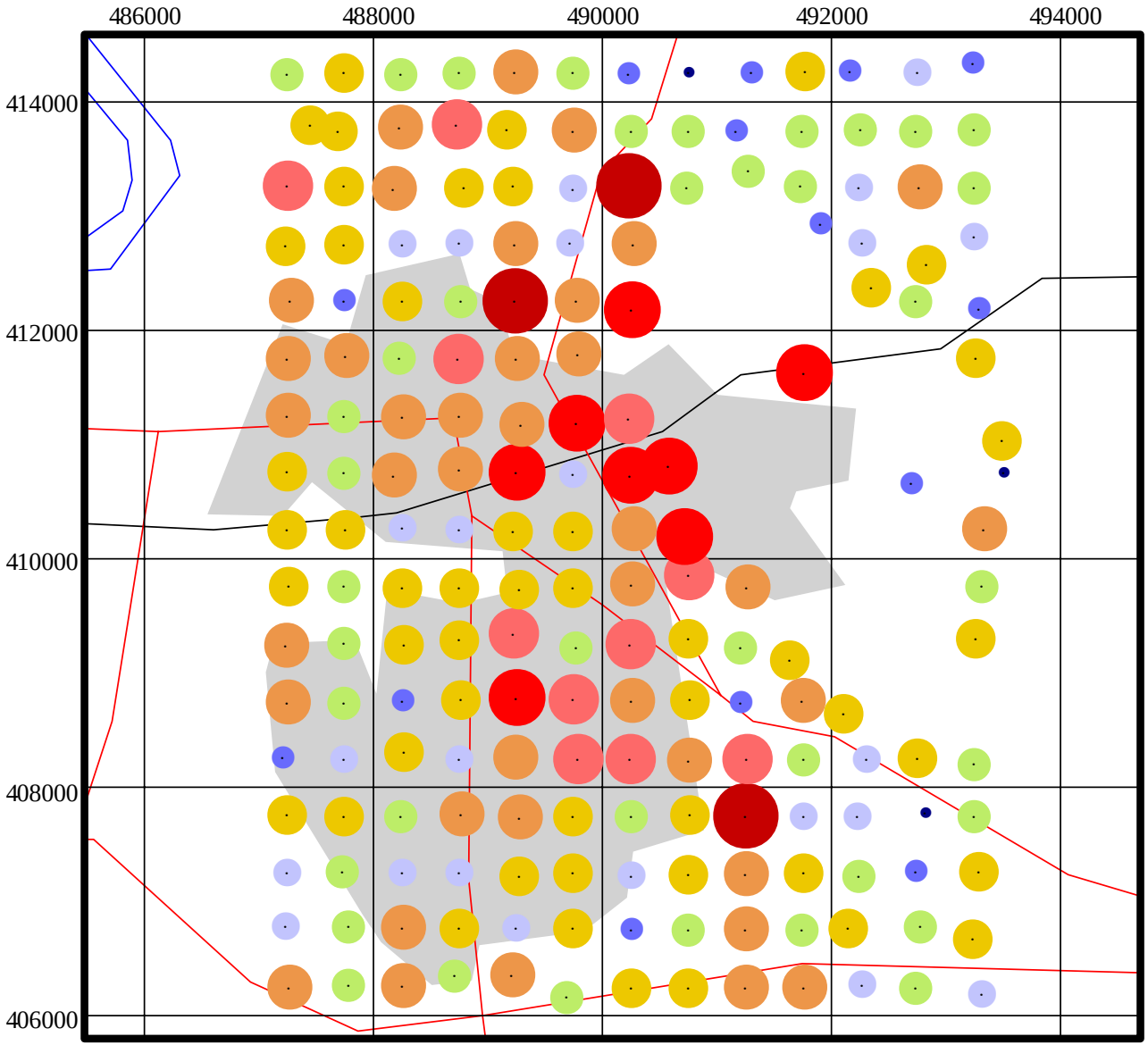
%ile	ppm
99	25
95	15
90	10
75	6
50	4
25	3
10	2

Sample locations
Major roads
Railways
Drainage
Urban area

surface soil	Sn (ppm)
number	196
minimum	0.5*
maximum	130
median	4
mean	6

* minimum value reported as half detection limit

Scunthorpe
Profile Soils
Tin

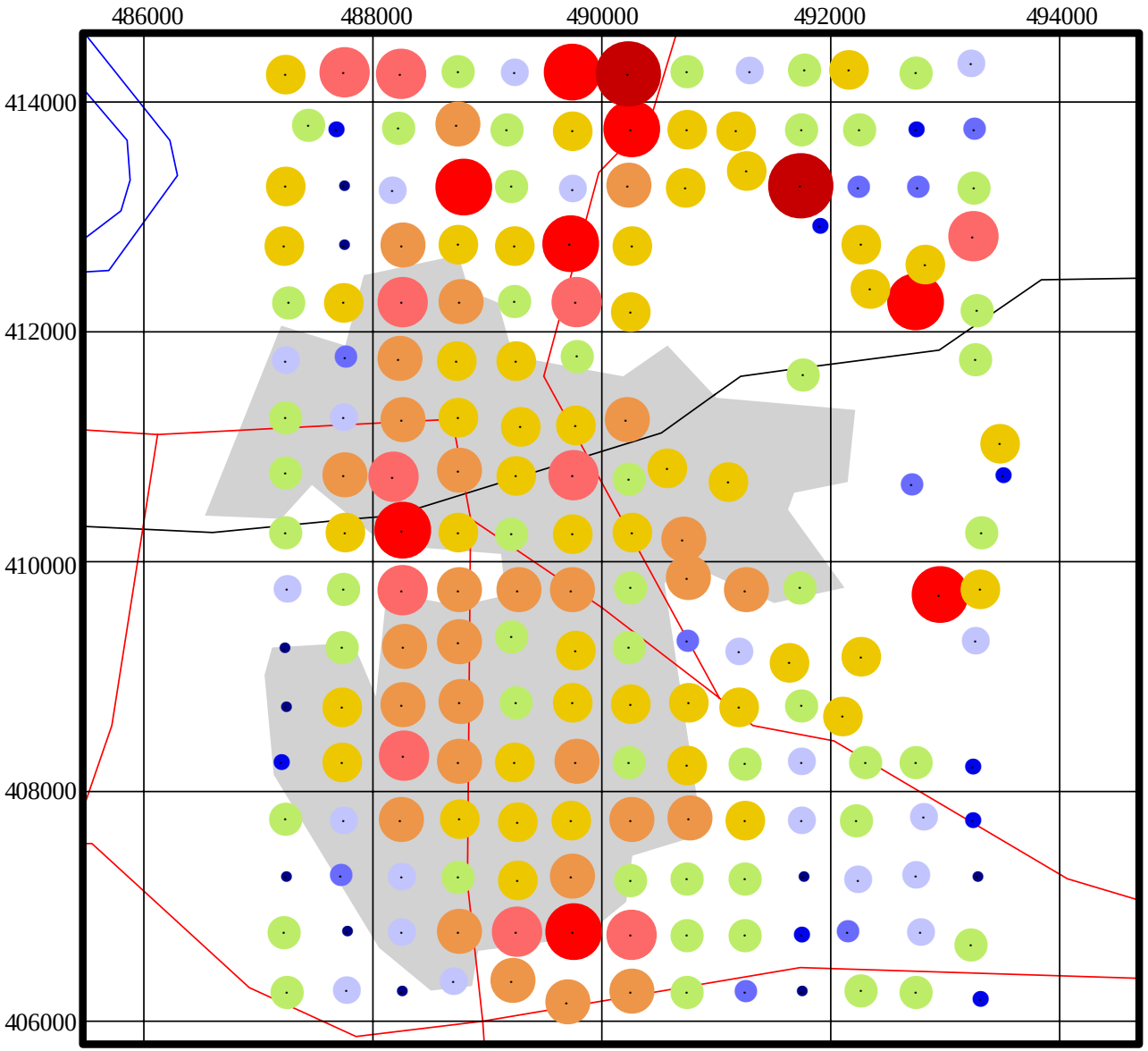


%ile	ppm
99	48
95	17
90	10
75	6
50	4
25	3
15	2
5	1

- Sample locations
- Major roads
- Railways
- Drainage
- Urban area

profile soil	Sn (ppm)
number	192
minimum	0.5*
maximum	159
median	4
mean	7

* minimum value reported as half detection limit



Scunthorpe

Surface Soils

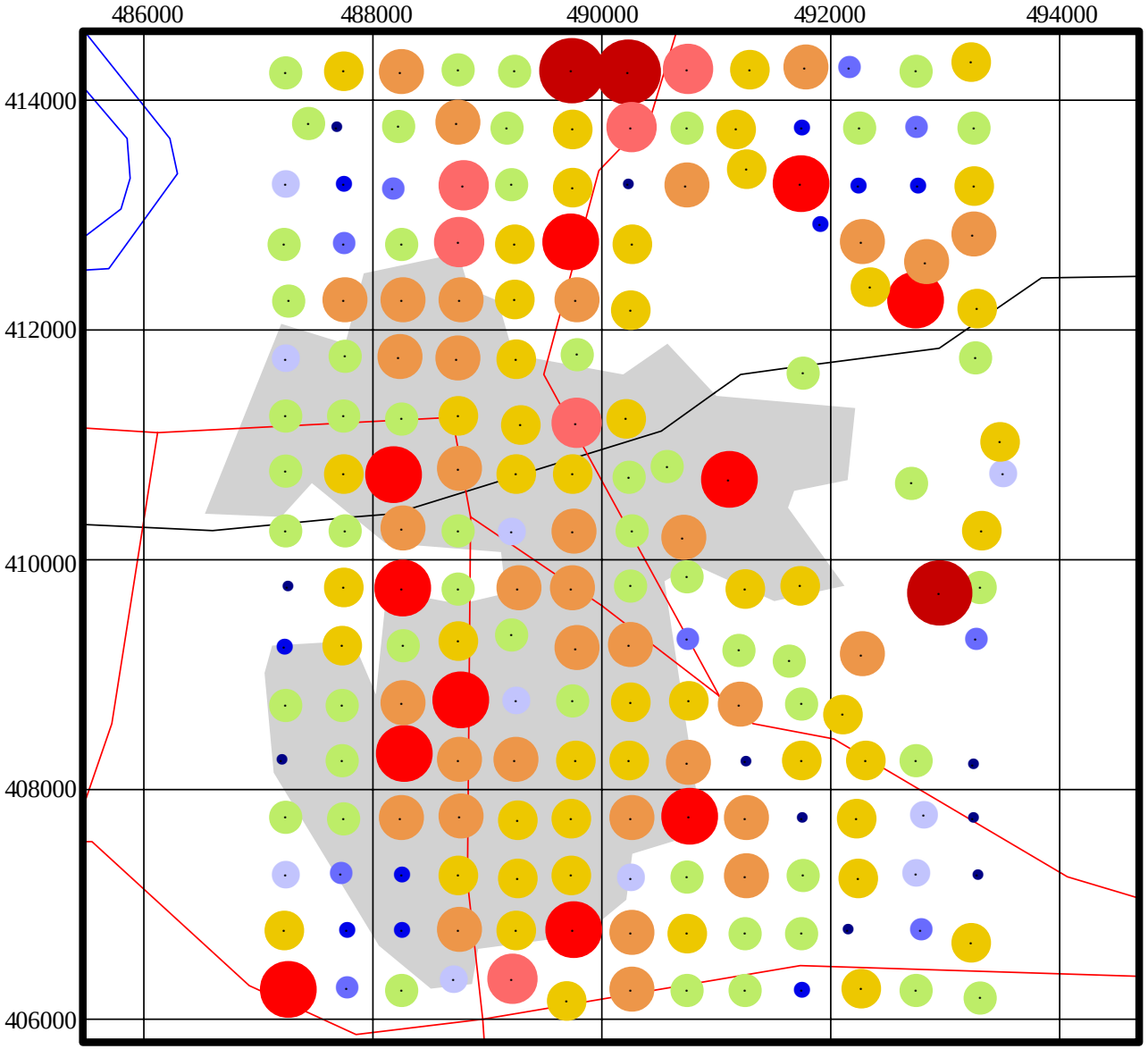
Titanium

%ile	WT %
99	0.788
95	0.572
90	0.535
75	0.411
50	0.268
25	0.177
15	0.156
10	0.143
5	0.125

Sample locations
Major roads
Railways
Drainage
Urban area

surface soil	TiO_2 (%)
number	196
minimum	0.098
maximum	0.975
median	0.268
mean	0.309

Titanium was not determined in the profile soils



Scunthorpe

Surface Soils

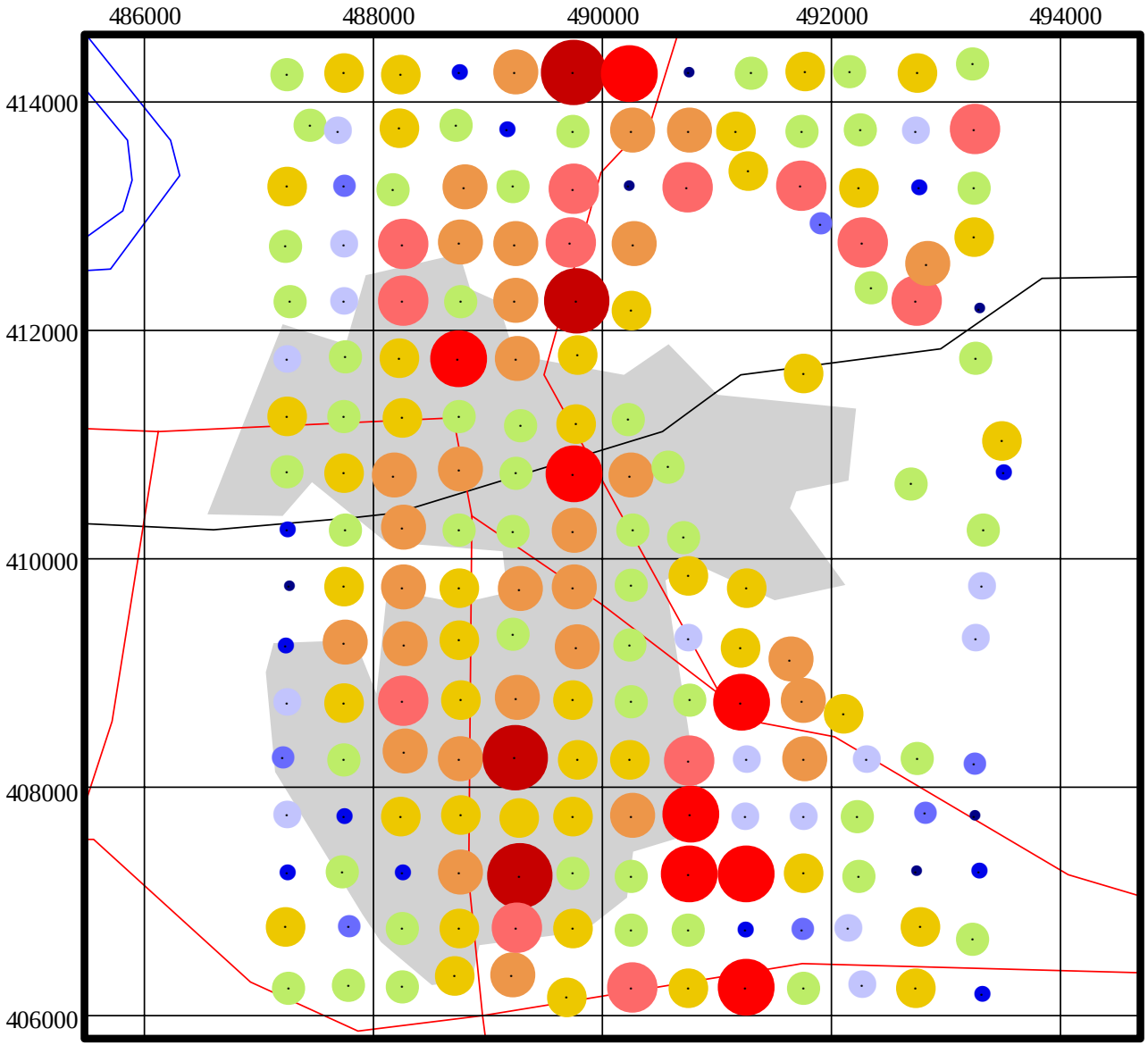
Uranium

%ile	ppm
99	2.9
95	2.1
90	2.0
75	1.6
50	1.2
25	0.8
15	0.7
10	0.6
5	0.4

Sample locations
Major roads
Railways
Drainage
Urban area

surface soil	U (ppm)
number	196
minimum	0.25*
maximum	3.9
median	1.2
mean	1.2

* minimum value reported as half detection limit



Scunthorpe

Profile Soils

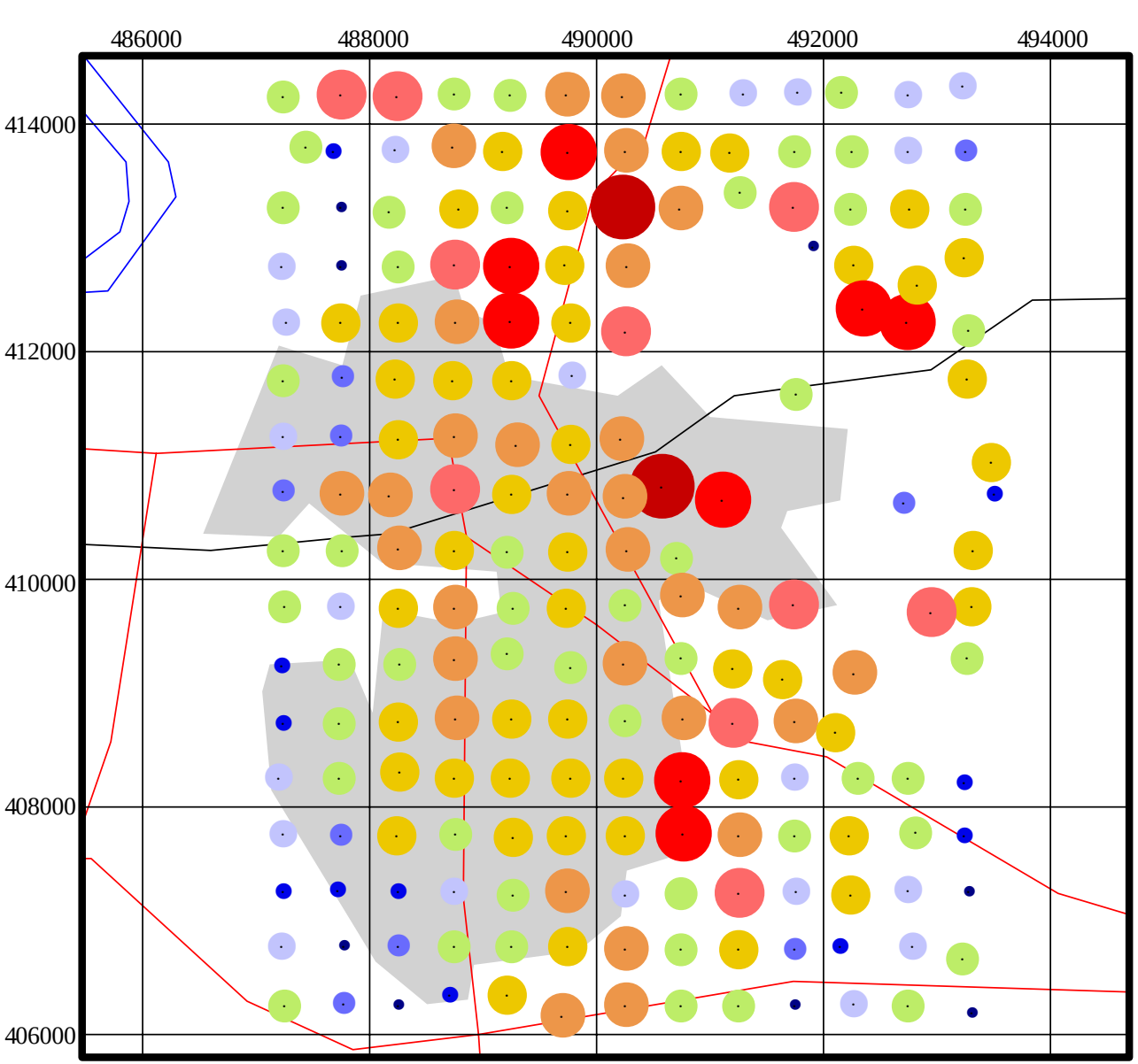
Uranium

%ile	ppm
99	3.4
95	2.9
90	2.7
75	2.3
50	1.9
25	1.4
15	1.0
10	0.9
5	0.7

Sample locations
Major roads
Railways
Drainage
Urban area

profile soil	U (ppm)
number	192
minimum	0.25*
maximum	3.5
median	1.9
mean	1.8

* minimum value reported as half detection limit



Scunthorpe

Surface Soils

Vanadium

%ile	ppm
99	493
95	268
90	197
75	138
50	86
25	53
15	42
10	39
5	30

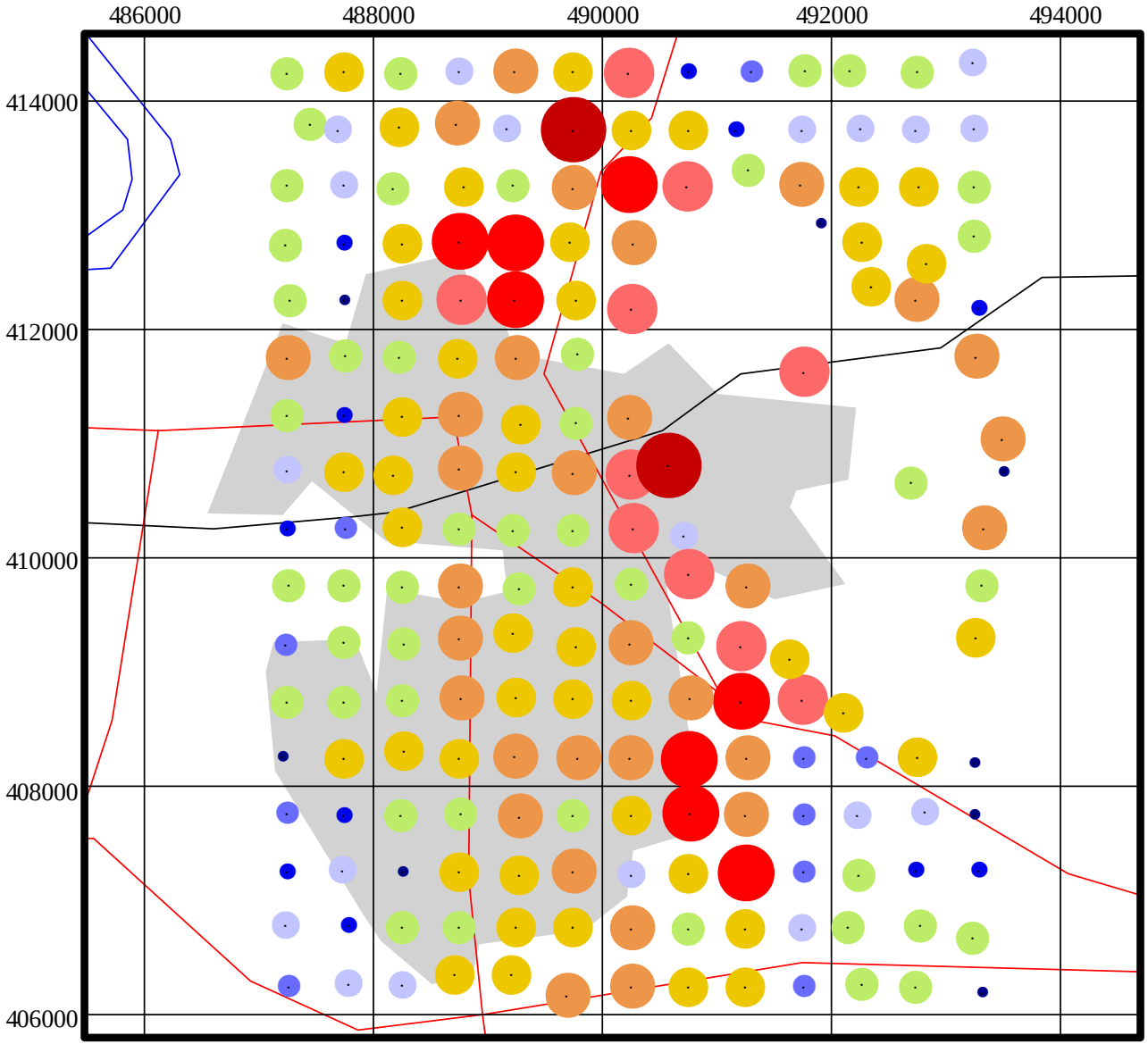
Sample locations
Major roads
Railways
Drainage
Urban area

surface soil	V (ppm)
number	196
minimum	21
maximum	646
median	86
mean	110

Scunthorpe

Profile Soils

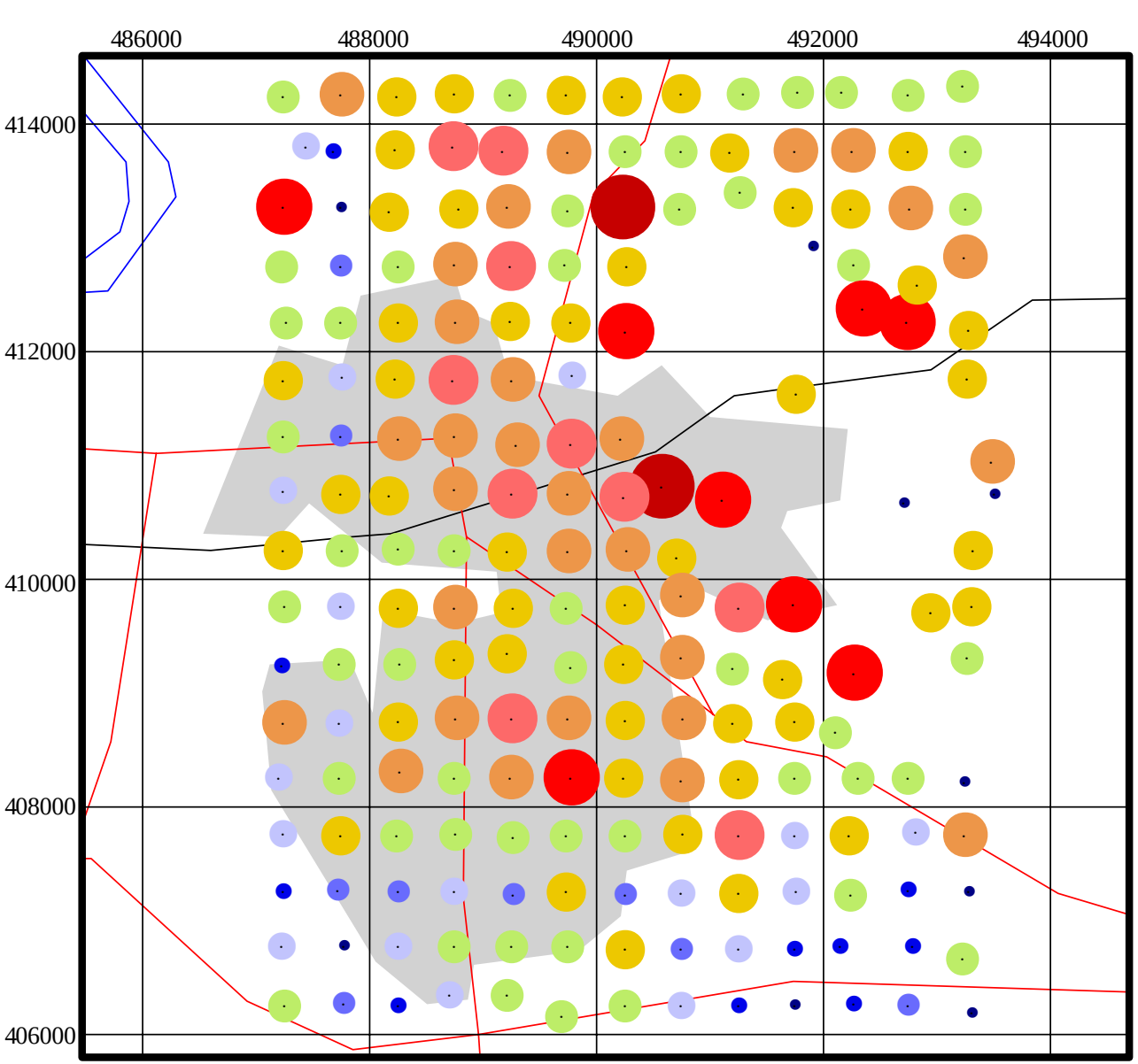
Vanadium



%ile	ppm
99	604
95	344
90	273
75	188
50	125
25	71
15	56
10	42
5	31

Sample locations
Major roads
Railways
Drainage
Urban area

profile soil	V (ppm)
number	192
minimum	26
maximum	686
median	125
mean	150



Scunthorpe

Surface Soils

Zinc

%ile	ppm
99	1707
95	404
90	230
75	138
50	79
25	45
15	34
10	29
5	22

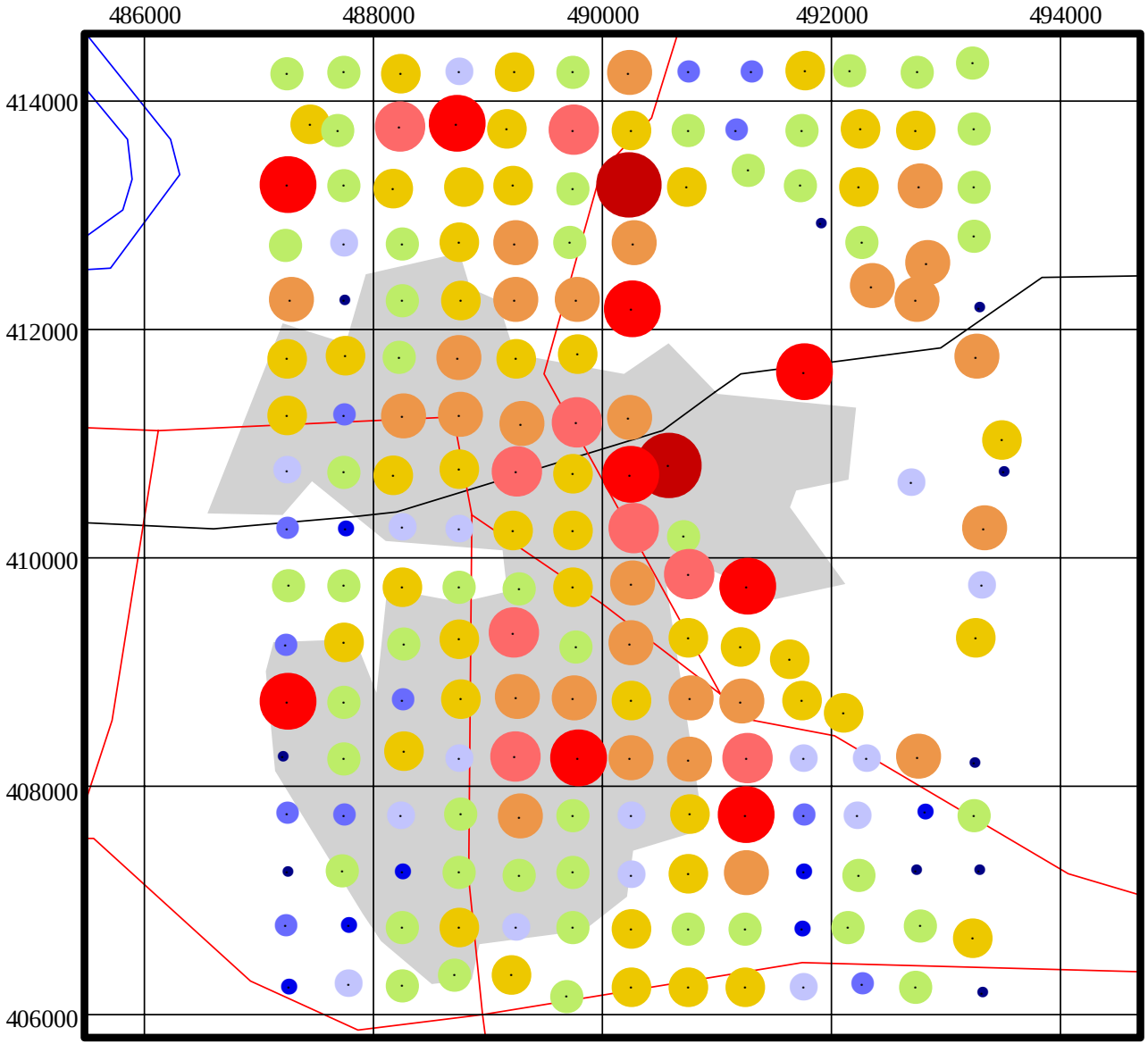
Sample locations
Major roads
Railways
Drainage
Urban area

surface soil	Zn (ppm)
number	196
minimum	10
maximum	10800
median	79
mean	190

Scunthorpe

Profile Soils

Zinc



%ile	ppm
99	1534
95	512
90	313
75	167
50	97
25	65
15	49
10	35
5	18

Sample locations
Major roads
Railways
Drainage
Urban area

profile soil	Zn (ppm)
number	192
minimum	10
maximum	15200
median	97
mean	240